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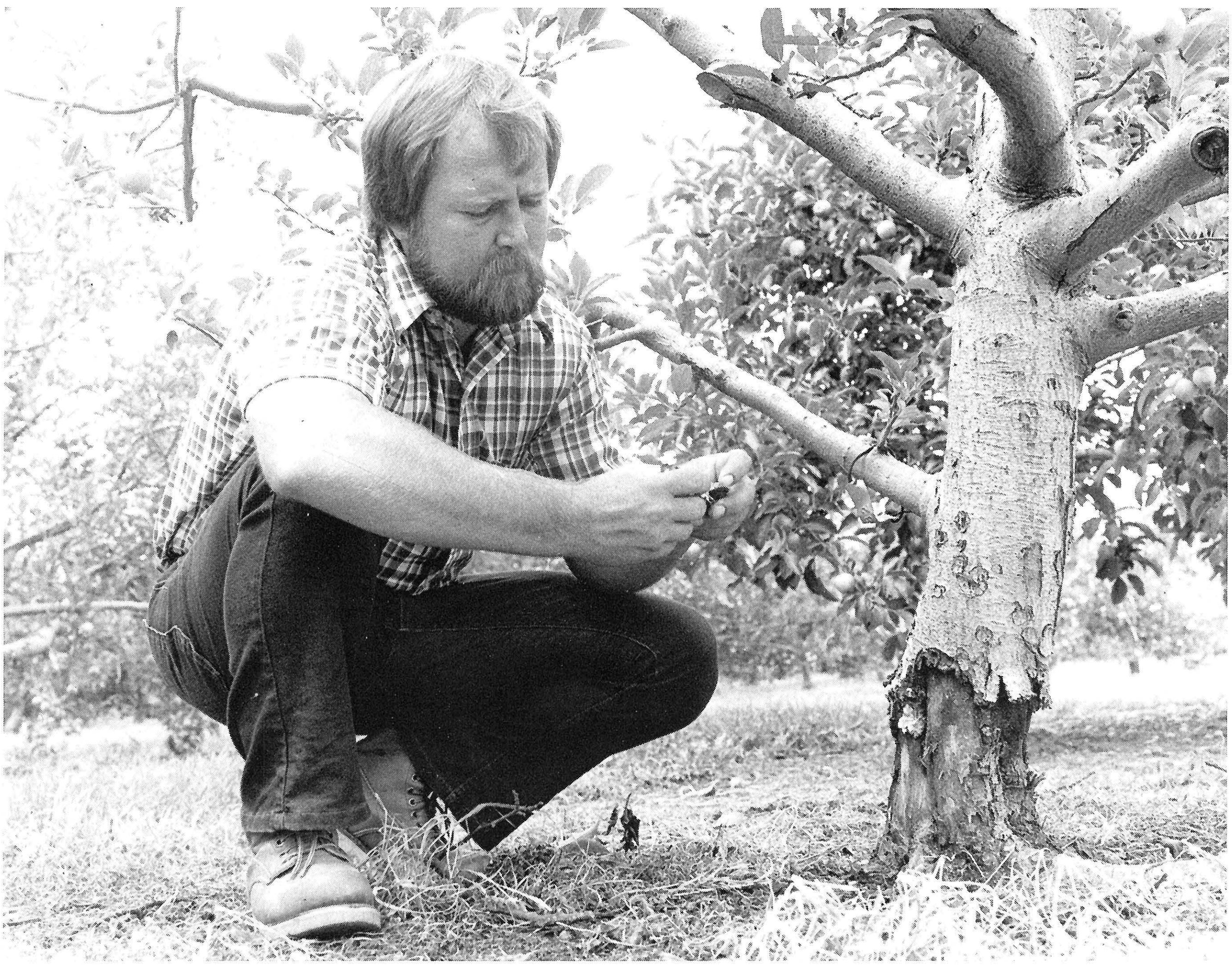
# Fruit Crops 1984: A Summary of Research



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**ON THE COVER:** Dr. Michael A. Ellis examines collar rot damage on apple tree.



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# Influence of Rootstock and Collar Rot Treatment on Growth, Yield, and Root Development of Golden Delicious Apple Trees

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## INTRODUCTION

Collar or crown rot caused by *Phytophthora cactorum* is a leading cause of tree death in Ohio apple orchards. Certain widely used rootstocks such as MM106 are particularly susceptible to this disease (6, 7). Greenhouse research on apple seedlings has demonstrated that container media containing composted hardwood bark has the ability to prevent infections of apple seedlings inoculated with the collar rot organism (5, 8). Although previous work on fungicide drenches or sprays applied to the soil or infected portions of the tree has not adequately controlled collar rot (6), recent work on orange (3) and apple (2) has indicated that the systemic fungicide metalaxyl (Ridomil 2E, Subdue) has been effective in controlling the disease on seedlings.

The current research was established to determine the effects of two soil-applied fungicides and composted hardwood bark on the control of collar rot and the influence of these treatments on tree growth and early cropping of apple trees in the field.

## MATERIALS AND METHODS

In 1979, 320 trees of Golden Delicious were planted 10 x 18 ft on a site with a history of tree loss due to collar rot. The rootstock treatments were: MM106, M9/MM106 ***out*** (6-inch interstem of M9 exposed above the soil line); M9/MM106 ***in*** (6-inch interstem of M9 half-buried beneath soil line). The collar rot treatments were: check (untreated); bark compost — a 12-inch deep planting hole dug with a 24-inch auger was filled with a 1:1 mixture of hardwood bark compost and field soil; captafol (Difolatan 4F); and metalaxyl (Ridomil 2E). Both chemicals at a rate of 500 ppm in water were applied as 1-liter drenches around the tree base in spring and fall of each year.

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Prior to application of the fungicides in 1979, half of all trees were inoculated with 10 ml of a 10,000 oospore suspension/ml of *P. cactorum*. Inoculations were repeated in September 1979 and April 1980. Black plastic collars (8 inches tall and 8 inches in diameter) were placed around the base of each tree and embedded in the soil 4 inches. The purpose of the collars was to contain the inoculum in close proximity to the tree crown to insure optimum conditions for infection. The collars were removed in September 1980.

The development of collar rot symptoms was recorded annually. As symptoms developed, isolations were made from diseased tissue to verify the presence of *P. cactorum*. Trunk circumference was recorded annually and yield/tree in 1982 and 1983.

Following harvest in 1983, tree height and spread were measured and the trees pulled using a tractor and chain. Soil was removed from the root systems and the distance was measured from the soil line to the first structural root (1 cm diameter or larger), the presence was noted of structural roots on the interstem (0 = none or 1 = structural roots present), and a rating was made of the amount of fine roots on the MM106 rootstock (smaller than 5 mm diameter) present (1 = none to 5 = many).

## RESULTS AND DISCUSSION

Very serious tree loss occurred with all rootstock and interstem positions when the soil around the trees was inoculated with the *P. cactorum* (Table 1). Bark compost caused a significant reduction in tree loss, but it still averaged 25% for the three rootstock types, which is probably unacceptable. Both chemicals used as drenches were successful in either preventing infection or keeping tree loss at a commercially acceptable level. Generally, tree loss occurred in the non-inoculated plots only when no preventive treatments were used. Tree loss in the non-inoculated check (no preventive treatment)

**TABLE 1.—Influence of Rootstock and Treatment for Collar Rot Control on Tree Loss of 'Golden Delicious' Apple Trees.**

| | Percent Tree Loss | | | | | |
|---|---|---|---|---|---|---|
| | Phytophthora cactorum | | | Non-inoculated | | |
| Treatment | MM106 | M9/MM106 In | M9/MM106 Out | MM106 | M9/MM106 In | M9/MM106 Out |
| Check | 92 | 83 | 67 | 8 | 25 | 17 |
| Bark Compost | 25 | 17 | 33 | 0 | 0 | 8 |
| Ridomil | 0 | 0 | 0 | 0 | 0 | 0 |
| Difolatan | 8 | 0 | 0 | 0 | 0 | 0 |

**TABLE 2.—Influence of Rootstock and Treatment for Collar Rot Control on Size and Productivity of 'Golden Delicious' Trees, 1983.**

| Rootstock | Average/Tree (ft) | | Area Trunk | Yield/Tree (lb) | | Yield Efficiency |
|---|---|---|---|---|---|---|
| | Height | Spread | ($cm^2$) | 1982 | 1983 | ($lb/cm^2$) |
| MM106 | 11.0a* | 9.3 | 45.7a | 9.4b | 93.7 | 2.25b |
| M9/MM106 (In) | 9.4b | 8.9 | 38.2b | 16.4a | 92.9 | 2.80a |
| M9/MM106 (Out) | 9.6b | 9.2 | 38.3b | 13.4b | 90.8 | 2.67a |
| Treatment | | | | | | |
| Check | 9.7 | 9.0 | 36.8c | 11.2 | 83.3b | 2.60 |
| Bark Compost | 10.2 | 9.3 | 45.4a | 15.1 | 104.3a | 2.61 |
| Ridomil | 10.2 | 9.1 | 41.4b | 11.4 | 91.6b | 2.48 |
| Difolatan | 9.9 | 9.2 | 39.3bc | 14.5 | 90.6b | 2.59 |

*Means with a letter in common are not different at the 5% level.

plots occurred at a relatively low, but still significant, level.

Burying the M9 interstem so that no MM106 tissue was present at the interface of the soil and trunk was not successful in decreasing infection with collar rot. In fact, these trees appeared slightly more susceptible to infections but the difference may not be significant.

The trees on MM106 were 14% taller than the interstem trees, but there were no differences in tree spread due to rootstock or treatment for collar rot control (Table 2). Trees on MM106 had larger trunk cross-sectional area [which is the most precise measure of overall tree growth (9)] than the interstem tree and depth of planting had no influence on this parameter. Costante and Lord (1) also found little influence of planting depth on overall tree size of interstem trees.

Trees planted with bark compost had a larger trunk cross-sectional area and more yield in 1983 than untreated or chemically treated trees. In a number of European countries which have difficulty in establishing orchards on sites previously planted to fruit crops, it has been reported that increased tree growth occurred when peat or spent mushroom compost was incorporated in the planting hole. We observed that the composted bark improved drainage and aeration in the immediate vicinity of the trunk.

Ridomil resulted in an increased trunk area compared to the untreated control. This may have been due to the slow decline of many of the inoculated check trees which ultimately succumbed to collar rot or to the reduction in either soil pathogens or pathogens in the trees that would be reduced due to the systemic nature of Ridomil. Generally, early yields and production efficiency were higher in the interstem trees compared to the larger trees on MM106. Similar results have been shown by many other investigators.

Since the information on the influence of the treatments for collar rot control was well defined, the study was terminated after 5 years and this provided an opportunity to look at root development on these trees. The use of the plastic collar around the trees and natural tree settling resulted in some of the interstems which were originally exposed above the soil line to be partially below the soil line at the end of the study. The presence of roots on the interstem was rated, with a value of 0 for no roots, 1 for a few roots, and 2 for many. No difference occurred according to the original interstem depth (***in*** = .70, ***out*** = .78) in the average presence of roots. Of course, interstems completely exposed above the soil line had no roots. The collar rot treatments had no effect on the amount of roots occurring on the interstem (Table 3).

Bark compost may have resulted in a greater amount of tree settling when the interstem was originally placed above the soil line, and thus resulted in an increase in structural root formation. It appeared that Ridomil encouraged structural root formation on the deep planted interstems and not on the exposed interstems, while the reverse was true for Difolatan. The reasons for these differences are not obvious.

The amount of fine roots was increased by placing

**TABLE 3.—Influence of Rootstock and Treatment for Collar Rot Control on Root Distribution of 1-Year-Old 'Golden Delicious' Trees, 1983.**

| Treatment | Roots on Interstem* | Structural Roots of Interstem† | | | Amount of Fine Roots‡ | Distance (cm) Soil Line to Structural Root |
|---|---|---|---|---|---|---|
| | | MM106 | M9/MM106 | | | |
| | | | In | Out | | |
| Check | 0.50 | 0.00c | 0.19bc | 0.14bc | 2.1b | 7.0 |
| Bark Compost | 0.62 | 0.00c | 0.12bc | 0.41a | 3.2a | 8.0 |
| Ridomil | 0.51 | 0.00c | 0.33ab | 0.08c | 2.1b | 8.5 |
| Difolatan | 0.43 | 0.00c | 0.04c | 0.33ab | 2.2b | 8.8 |

*Rating of roots on interstem: 0 = none, 1 = few, 2 = many.
†Rating: 0 = no structural roots (roots 1 cm diameter and larger), 1 = structural root present.
‡Rating: 1 = none to 5 = many fine roots (smaller than 5 cm diameter).

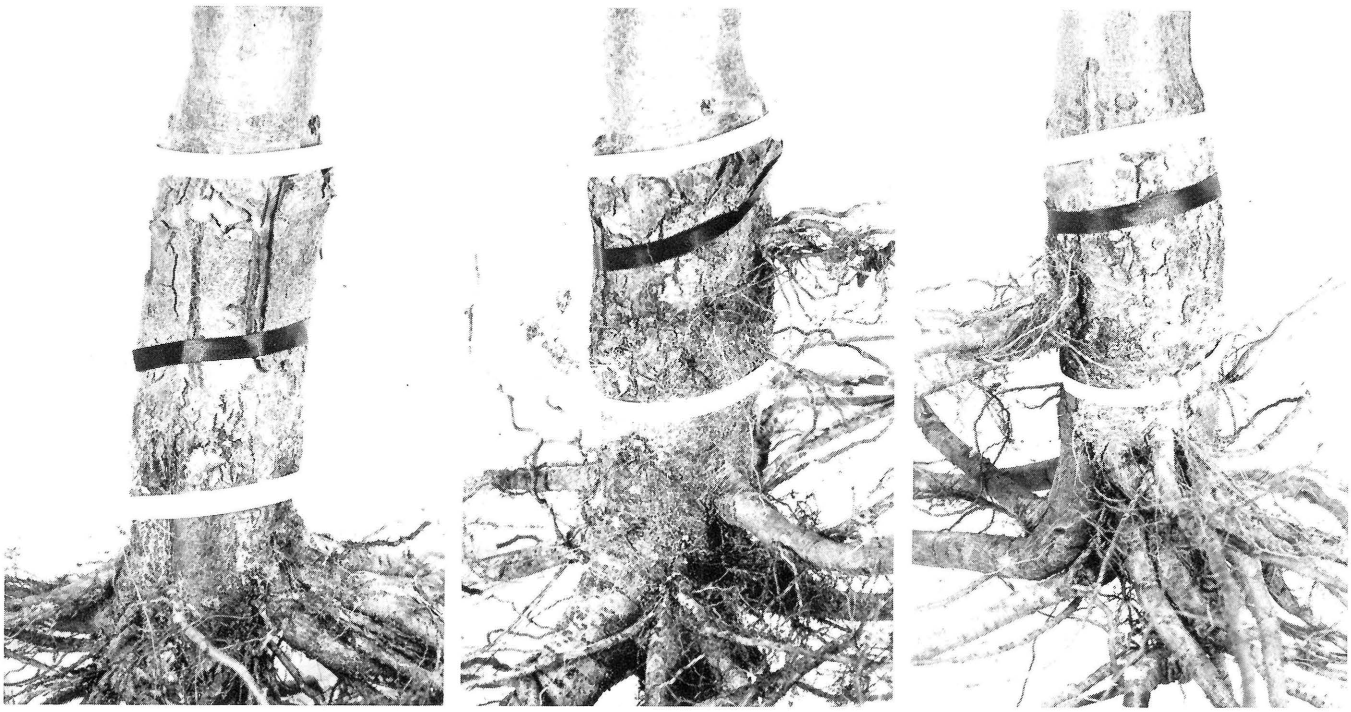

FIG. 1.—Variability in root formation on M9 interstems (outlined by white tape), showing no roots (left), fine roots (center), and structural roots (right) below the soil line (black tape).

bark compost in the hole, and this factor may have a direct relationship to the improved growth and fruiting of these trees (Table 2). Trees on MM106 (rating of 2.9) had slightly more fine roots present than interstem trees (rating of 2.1). The collar rot treatments had no influence on the distance from the soil line to the uppermost structural root, but trees on MM106 had shallower structural roots (5.4 cm) than interstem trees (9.4 cm).

Previous reports (1) indicate that roots may occur on M9 interstems planted partially below the soil surface. The data provided here (Table 3) confirm that report, but not all submerged interstems root (Fig. 1) and generally the roots were small and rather sparse (center photo). However, larger structural roots occasionally occurred (right photo), but no pattern was present as to the factors which may encourage their development. Generally, tree size of interstem trees is more variable than conventional two-piece trees on clonal rootstock. This variability is generally related to differences in interstem length or burknots, but when the interstem is partially buried, root formation may also play a role.

Interstem trees often sucker badly and the degree of suckering varies with rootstock (4). Very few rootsuckers were produced in this particular planting, but generally when suckers did form (Fig. 2) they occurred on trees with the interstem completely exposed above the soil line. Costante and Lord (1) also found an increase in suckering when the entire interstem was exposed.

The two fungicides tested in this study show real potential for preventing the development of collar rot

FIG. 2.—Rootsucker formation on M9/MM106 interstem trees, showing formation near the soil surfaces at the lower graft union of the interstem.

under very severe disease pressure. Composted bark also had a significant but lesser effect. The placement of M9 interstems either exposed or partially submerged below the soil line does not have an influence on tree loss to collar rot under the conditions of this study. The presence of root development on deep-planted M9 interstem is documented, but generally structural roots occurred at greater depths on interstem trees than on two-piece trees on MM106.

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# Effects of Application Method on Uptake of Metalaxyl (Ridomil 2E) by Apple Trees

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## INTRODUCTION

Collar rot of apple is caused by the fungus *Phytophthora cactorum* (Leb. & Cohn). Several other *Phytophtora* species also have been associated with the disease (6). Disease incidence is generally greater in heavy and poorly drained soils (1, 8). Differences in susceptibility of various apple rootstocks have been reported (9); however, few apple cultivars or commercially used clonal rootstocks are considered highly resistant (7, 9), and the reports are inconsistent.

The most effective means of controlling the disease have been the selection and use of the more resistant rootstocks and well-drained planting sites which are not conducive to disease development. Until recently, fungicide drenches or sprays applied to soil or infected portions of the tree have not provided adequate control (5). The introduction of new fungicides such as metalaxyl (Ridomil 2E) which are highly effective against pythiacious fungi, as well as systemic in plants, could result in effective chemical control (2, 3, 4, 10).

Based on research conducted in Ohio, Ridomil 2E received a 24 C (special local need) label for control of collar rot on nonbearing apples. The Ohio label states that the fungicide solution is to be applied to the soil around the trunk of each tree. Greenhouse studies have shown that when Ridomil is applied in this manner, it is taken up by the tree and translocated upwards (3). This systemic activity is undoubtedly one factor which makes this treatment efficacious for collar rot control.

Since the use of Ridomil on apple was initiated, many questions have been raised in relation to application methodology. Many persons feel that a broadcast treatment (under the entire canopy of the tree) may be more efficacious than a drench directed at the base of the tree.

The purpose of this study was to determine uptake of Ridomil by apple trees following a broadcast application to soil under the entire tree canopy and a drench to the soil and tree trunk at the base of the tree.

## MATERIALS AND METHODS

### Test Sites

Four orchard sites were selected for this study. Site location, tree cultivar, rootstock, and age of planting were:

**Site 1:** Snyder Farm (OARDC), Jonathan, C-6 interstem with seedling rootstock, 7 years old.

**Site 2:** Snyder Farm (OARDC), Delicious, 106 rootstock, 15 years old.

**Site 3:** Snyder Farm (OARDC), Cortland, seedling rootstock, 30 years old.

**Site 4:** Horticulture Unit II (OARDC), Golden Delicious, 106 rootstock with an M-9 interstem, 4 years old.

These sites were selected because they represent the three most common tree sizes or production systems found in the United States at present. The Jonathan and Golden Delicious trees were dwarf (8-9 feet tall), the Delicious trees were semi-dwarf (12-15 feet tall), and the Cortlands were full-size trees (25-30 feet tall).

### Treatments

**Broadcast — under the tree canopy:** Ridomil 2E was applied at the rates of 2, 4, and 8 lb A.I./acre in 40 gal of water per acre to the entire soil surface under the tree canopy. The 8 lb A.I. per acre rate was also applied in 200 gal of water per acre.

The area under each tree was calculated and the appropriate amount of Ridomil was applied in the appropriate amount of water with a $CO^2$ pressurized sprayer at 40 p.s.i. The solution was distributed evenly over the soil under the entire tree canopy (out to the drip line).

**Drench — applied to soil and tree trunk at base of tree:** Ridomil was applied at the 2 and 4 lb A.I. per acre rates. The same amounts of material used per tree in the 2 and 4 lb per acre broadcast treatments were applied to each tree in 2 qt water. Fungicide solutions were poured around the trunk of each tree so that soil and tree bark at the base of the tree were moistened.

### Experimental Design

All treatments consisted of four single-tree replications for each fungicide rate and method of application. Treatments were arranged in a completely randomized design.

All treatments were applied in the Jonathan and Golden Delicious orchards. The Delicious and Cortland orchards received only the 8 lb A.I./A rate in 200 gal of water per acre and the 4 lb A.I./A rate as a drench to the base of the tree in 2 qt water. Nontreated trees served as controls in all orchards.

### Qualitative Assay to Determine Uptake of Ridomil by Apple Trees

All treatments were applied on May 16, 1983. Prior to treatment, wooden plugs were cut from opposite sides of each tree at a distance of 5 to 10 cm above the soil line. Plugs were cut using an increment hammer (Forestry Supplies, Inc., 205 W. Rankin St., P. O. Box 8397, Jackson, MS 39204, Catalog No. 59690). Plugs were approximately 1.5 cm long and 4 mm wide. A 5 mm section was cut from each plug. The bark was removed

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**TABLE 1.—Presence of Metalaxyl in Apple Wood Following Broadcast and Drench Applications of Ridomil 2E (Jonathan).**

| Treatment | Percentage of Plugs with Metalaxyl Present (No Growth)* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Sampling Date and Number of Days After Application | | | | | | | |
| | May 16<br>0 | May 23<br>7 | May 31<br>14 | June 6<br>22 | June 15<br>29 | June 29<br>43 | July 29<br>71 | August 29<br>101 |
| Check nontreated | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ridomil 2 lb a.i./A Broadcast under canopy 40 gal water/A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ridomil 4 lb a.i./A Broadcast under canopy 40 gal water/A | 0 | 0 | 0 | 13 | 0 | 0 | 0 | 0 |
| Ridomil 8 lb a.i./A Broadcast under canopy 40 gal water/A | 0 | 0 | 0 | 13 | 13 | 13 | 0 | 0 |
| Ridomil 8 lb a.i./A Broadcast under canopy 200 gal water/A | 0 | 0 | 0 | 13 | 13 | 0 | 0 | 0 |
| Ridomil 2 lb a.i./A Drench on trunk 2 qt water | 0 | 63 | 88 | 100 | 88 | 88 | 50 | 18 |
| Ridomil 4 lb a.i./A Drench on trunk 2 qt water | 0 | 75 | 100 | 100 | 88 | 88 | 75 | 13 |

*Based on eight plugs (two per tree or replication) per treatment and time of sampling.

**TABLE 2.—Presence of Metalaxyl in Apple Wood Following Broadcast and Drench Applications of Ridomil 2E (Golden Delicious).**

| Treatment | Percentage of Plugs with Metalaxyl Present (No Growth)* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Sampling Date and Number of Days After Application | | | | | | | |
| | May 16<br>0 | May 23<br>7 | May 31<br>14 | June 9<br>22 | June 15<br>29 | June 29<br>43 | July 29<br>71 | August 29<br>101 |
| Check nontreated | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ridomil 2 lb a.i./A Broadcast under canopy 40 gal water/A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ridomil 4 lb a.i./A Broadcast under canopy 40 gal water/A | 0 | 0 | 0 | 25 | 25 | 25 | 0 | 0 |
| Ridomil 8 lb a.i./A Broadcast under canopy 40 gal water/A | 0 | 0 | 25 | 13 | 38 | 38 | 25 | 13 |
| Ridomil 8 lb a.i./A Broadcast under canopy 200 gal water/A | 0 | 0 | 25 | 50 | 38 | 50 | 13 | 0 |
| Ridomil 2 lb a.i./A Drench on trunk 2 qt water | 0 | 63 | 88 | 100 | 88 | 75 | 63 | 13 |
| Ridomil 4 lb a.i./A Drench on trunk 2 qt water | 0 | 75 | 100 | 88 | 100 | 88 | 75 | 25 |

*Based on eight plugs (two per tree or replication) per treatment and time of sampling.

and sections were cut so that they contained only secondary xylem. All sections were sterilized by autoclaving at 121° C for 20 min at 15 p.s.i. Each section was then placed on end in the center of a 100 x 15 mm plastic petri dish containing 15 ml of lima bean agar (LBA) (11).

Agar plugs (approximately 2 x 2 mm) which were colonized by *P. cactorum* were cut from the edge of 5-day-old cultures of *P. cactorum* on LBA. One colonized agar plug was placed on the end of each plug section. Plates were closed and incubated for 3 days at 24° C. Fungal growth on agar plugs and wooden plug sections was recorded. No growth on plugs indicated that sufficient Ridomil was in the wood to inhibit growth of *P. cactorum*. A similar technique was used previously in greenhouse studies (3).

### Sampling Dates

Initial treatments were applied on May 16, 1983. Additional sampling dates and the number of days after treatment were: May 23, 7 days; May 31, 14 days; June 8, 22 days; June 15, 29 days; June 29, 43 days; July 29, 71 days; and August 29, 101 days.

## RESULTS AND DISCUSSION

At all rates tested, the broadcast application of Ridomil resulted in little or no uptake of metalaxyl by apple trees (Tables 1-4). These results are similar to those reported by Davis (2) on citrus.

Application of Ridomil as a drench to the soil and bark at the base of the tree appeared to be an effective treatment for introducing metalaxyl into the tree. Ridomil was detected in the largest percentage of trees within 2 weeks after the trunk drench application. Ridomil could be detected in some trees for up to 14 weeks after treatment. It is doubtful that the fungicide was taken up by roots following the drench to the trunk, because most feeder roots are in the region of the drip line. It is highly probable that placement of the fungicide at the base of the tree and in contact with the trunk facilitated movement of the fungicide directly through the bark into the tree. Davis (2) reported that trunk paints of metalaxyl were more effective in moving fungicide into the tree than soil drenches on 5-year-old citrus trees.

In collar rot, invasion occurs at the soil line on the tree trunk and the fungus moves laterally and longitudinally and can eventually girdle and kill the tree. In crown rot, invasion is below ground in the region where major roots emerge from the lower trunk and the infection extends distally along the primary roots (6). In neither case are feeder roots affected by these diseases.

The only reason for making broadcast (under the

**TABLE 3.—Presence of Metalaxyl in Apple Wood Following Broadcast and Drench Applications of Ridomil 2E (Delicious).**

| | Percentage of Plugs with Metalaxyl Present (No Growth)* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Sampling Date and Number of Days After Application | | | | | | | |
| **Treatment** | May 16<br>0 | May 23<br>7 | May 31<br>14 | June 8<br>22 | June 15<br>29 | June 29<br>43 | July 29<br>71 | August 29<br>101 |
| Check nontreated | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ridomil 8 lb a.i./A Broadcast under canopy 200 gal water/A | 0 | 25 | 13 | 37 | 25 | 37 | 13 | 0 |
| Ridomil 4 lb a.i./A Drench on trunk 2 qt water/tree | 0 | 100 | 100 | 100 | 100 | 75 | 63 | 25 |

*Based on eight plugs (two per tree or replication) per treatment and time of sampling.

**TABLE 4.—Presence of Metalaxyl in Apple Wood Following Broadcast and Drench Applications of Ridomil 2E (Cortland).**

| | Percentage of Plugs with Metalaxyl Present (No Growth)* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Sampling Date and Number of Days After Application | | | | | | | |
| **Treatment** | May 16<br>0 | May 23<br>7 | May 31<br>14 | June 8<br>22 | June 15<br>29 | June 29<br>43 | July 29<br>71 | August 29<br>101 |
| Check nontreated | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ridomil 8 lb a.i./A Broadcast under canopy 200 gal water/A | 0 | 0 | 0 | 0 | 13 | 25 | 0 | 0 |
| Ridomil 4 lb a.i./A Drench on trunk 2 qt water/tree | 0 | 100 | 100 | 100 | 100 | 75 | 50 | 13 |

*Based on eight plugs (two per tree or replication) per treatment and time of sampling.

entire tree canopy) applications of Ridomil on apple would be to facilitate uptake of the fungicide by feeder roots and translocation to the trunk region where disease develops and causes damage. Our results indicate that broadcast treatments do not facilitate uptake of metalaxyl by apple trees. The reason for this is not known but it may be partially due to our relatively heavy soils.

It appears that the most effective method of applying Ridomil to apple trees for control of collar rot is a drench applied to the base of the tree. In applying this drench, the tree trunk is also treated. The fungicide apparently moves directly into the tree through the bark and is applied to the area of the tree where disease development occurs.

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# The Influence of Light Environment Early in the Season on Bloom, Fruit Development, and Return Bloom of 'Starkrimson' Red Delicious Grown in a Greenhouse

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## INTRODUCTION

The light environment in which a fruit develops will affect its size, shape, and quality. Several reports have evaluated the influence of light on fruit development in the growing season after fruit set and fruit cell division have occurred (2, 12, 14). However, light may be limiting earlier in the season due to environmental conditions, poor tree training or pruning, or inadequate spur leaf area to absorb radiation.

Hansen (13) noted that the "greater part by far" of total growth in new fruits was based upon current photosynthates rather than reserves. Dennis (7) reported that fruit set of 'Delicious' in several orchard sites was significantly correlated to light in the 3 weeks prior to bloom. Shaw (20) found that fruit shape was determined within 16 days after bloom. Therefore, it is obvious that the environment immediately surrounding the bloom period is critical to the subsequent performance of the tree. During this early period of growth, spur leaves comprise the majority of the tree canopy.

This study was designed to determine the effects of the light environment early in the season on the role of spur leaves in fruit set, size, shape, quality, and subsequent bloom.

## MATERIALS AND METHODS

Small 'Starkrimson'/MM106 trees were grown in 3-liter pots containing a Wooster silt loam and Pro-mix B media (1:1 v/v). Trees had cropped the previous season and were put into dormant cold storage (<5° C) for approximately 150 days. After storage, trees were placed in a cool greenhouse and sprayed with a superior dormant oil prior to bud break. The glass greenhouse was covered with a double layer of air-supported Monsanto 602 polyethylene film. Temperatures were thermostatically controlled in a range of 8-28° C and air-cooled by fan and wet aspen pads.

Each plant was fertilized with 15 g 14.0 N-6.1 P-11.6 K Osmocote fertilizer and 500 ml of a soluble trace element mineral fertilizer. Trees were watered as required and given supplementary soluble fertilizer containing 10 g/l of 20.0 N-8.7 P-16.6 K at about 45-day intervals. Sprays were applied as needed to control mites and other insects. Approximately 2 weeks after trees were placed in the greenhouse, buds started to break at which time treatments were begun.

Treatments consisted of three light environments: 1) control, greenhouse ambient; 2) shade; and 3) increased light during four periods early in the season as follows: A) budbreak to fruit set (BB-FS), B) budbreak to petal fall (BB-PF), C) tight cluster to petal fall (TC-PF), and D) petal fall to fruit set (PF-FS) (Table 1). Fifty-five percent shade was provided by black polypropylene shade fabric (Chicopee Lumite). Increased light was provided by five General Electric H.I.D. lamps with lucalox bulbs (G.E. L.U. 400, high pressure sodium), placed 1.5 m above plant tops. Lamps were on only during daylight hours. Reflective white plastic was placed underneath trees in the increased-light environment.

The light and shade areas were 2 m x 3 m in size, while the control environment was 3 m x 4 m in size. Eight replications of whole tree treatments were randomly assigned with two or three sample spurs per tree. Trees were randomly placed and uniformly spaced to avoid crowding within each light environment. Trees were moved from one light environment to another during the appropriate period (Table 1).

Light was measured daily in four replicate locations in each environment by Li-Cor integrators with PAR (400-700 nm) quantum sensors and compared to ambient outdoor light to determine percent full sun (Table 1). Light sensors were placed 15 cm above pots approximately in a mid-tree location. Temperature of each environment was recorded daily by chart hygrothermographs. Degree hour units were calculated to indicate length of time above 10°, 15.5°, and 21° C (Table 1).

Flowers were pollinated twice daily with a variety of apple and crabapple pollen.

Treatments were discontinued 34 days after petal fall, and trees were randomly placed into a uniform environment. Clusters were thinned to one fruit per spur. Fruit removed was quickly frozen on dry ice, lyphoлized, ground in a Wylie mill with a No. 20 mesh screen, and stored at -29° C. Sorbitol and water soluble sugars were extracted in a boiling bath (100° C) for 10 minutes, centrifuged, and filtered. The insoluble pellet was hydrolyzed with takadiatase (21). Sorbitol concentration of the extract was determined by a modified enzyme procedure (4). Extracted soluble reducing sugars and takadiatase hydrolyzed starch (21) concentration were determined by a modified ferricyanide method (15).

Fruit diameter was measured biweekly with vernier caliper and fruit was harvested 155 days after petal fall. Fruit color was rated by two individual observations compared with a photographic standard on a scale of 1 (100% red) to 5 (<60% red). Firmness was measured with a 1 cm penetrometer on two sides of each fruit. Soluble solids were measured with a Bausch and Lomb refractometer. A mid-fruit cortical cross-section was forced-

[1]Graduate Research Associate and Professor, respectively, Dept. of Horticulture.

**TABLE 1.—Treatment Environmental Conditions During Four Growth Periods of 'Starkrimson' Delicious Trees Grown in a Greenhouse.**

| | Experimental Conditions | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Percent Full Sun | Treatment | Days in | Total Percent | Mean Daily Temperature (°C)* | | | Degree (°C) Hours Above | | |
| Treatment | of Treatment* | Percent† | Treatment‡ | Full Sun | High | Low | Av. | 10° | 15.5° | 21° |
| Control | 35.4b | BB-FS | 75 | 35 | 22.2b | 11.3 | 16.8b | 1395 | 710 | 230 |
| Shade | 15.8c | BB-FS | 75 | 16 | 20.7c | 11.6 | 16.2c | 1289 | 582 | 125 |
| Light | 65.0a | BB-FS | 75 | 65 | 25.1a | 11.5 | 18.3a | 1343 | 706 | 267 |
| Shade | 15.8c | BB-PF | 41 | 19 | | | | 1315 | 657 | 196 |
| Light | 65.0a | BB-PF | 41 | 53 | | | | 1384 | 763 | 271 |
| Shade | 15.8c | TC-PF | 21 | 30 | | | | 1355 | 667 | 201 |
| Light | 65.0a | TC-PF | 21 | 46 | | | | 1372 | 736 | 264 |
| Shade | 15.8c | PF-FS | 34 | 26 | | | | 1345 | 635 | 157 |
| Light | 65.0a | PF-FS | 34 | 48 | | | | 1330 | 653 | 224 |

*Mean separation within columns by LSD, 5%.
†BB = bud break, TC = tight cluster, PF = petal fall, FS = fruit set.
‡Days in light environment (light or shade). The remainder of experimental period (total 75 days) in control.

air dried at 78° C for 20 days for percent dry weight measurement.

# RESULTS AND DISCUSSION

## Experimental Conditions

Ambient light conditions were only 35% of outdoor full sun (Table 1). Shade reduced light (16% full sun) and H.I.D. lamps increased light (65% full sun). Mean daily high temperatures and average temperatures were increased under the lamps and decreased under the shade, while average low (night) temperatures were unaffected. Average daily high temperatures increased throughout the 75-day experimental period, with temperatures during the PF-FS period being greater than during the BB-TC or TC-PF periods (data not presented).

Correlation coefficients of environmental parameters and experimental variables are presented in Table 5. Degree hour units > 21° C were well correlated to percent full sun, with light accounting for 71% of high temperature variation. However, degree hour units (dhu) > 10° C were relatively independent of light treatment, accounting for only 25% of temperature variation.

## Bloom Stage

The date of bloom was delayed 3-4 days by the BB-FS shade treatment and 1-2 days by the TC-PF shade treatment (Table 2). Bloom date of mature 'Delicious' trees in the field was unaffected by 63% shade or 20% increased light treatments applied at tight cluster (8). Removal of spur leaves of 'Cox Orange Pippin' before bloom had no influence on bloom date (1). However, removal of spur leaves coupled with a 3-mm bark girdle on the spur reduced flower petal size by 60% (11), indicating the importance of spur leaf assimilates or metabolites in bloom development.

Although there may be a light effect on bloom development, as indicated by correlation coefficient (r = .898), the effect is generally confounded by temperature influences. Several reports indicate bloom is delayed by decreasing temperatures (6) or is earlier following high temperatures (16).

## Fruitlets 34 Days After Petal Fall (APF)

The number of flowers per spur was unaffected by treatments, since flower initiation and differentiation occurred the previous season (Table 3). Shade during the BB-FS, BB-PF, and PF-FS periods resulted in reduced fruit number per spur compared to increased light during the same period. Shade at BB-FS or PF-FS reduced fruit set compared to increased light treatments. Although shade at any period tended to reduce set, it was only significantly lower than control when applied for the entire period from BB-FS. Increasing light during any period did not significantly increase fruit per spur or set compared to the ambient greenhouse condition (control 35% full sun). Set was significantly correlated to light (r = .670) and high temperature (r = .822) (Table 5).

**TABLE 2.—Influence of Light Environment During Two Periods on Bloom Stage of Potted 'Starkrimson' Red Delicious Spurs.***

| | | Bloom Stage‡ Days After Budbreak | | | | | |
|---|---|---|---|---|---|---|---|
| Treatment | Period† | 27 | 29 | 31 | 33 | 35 | 37 |
| Control | BB-FS | 3.8b | 4.2ab | 5.0ab | 5.2b | 5.7ab | 5.9a |
| Shade | BB-FS | 2.9d | 2.9c | 4.3c | 4.8c | 5.1c | 5.6b |
| Light | BB-FS | 4.2a | 4.7a | 5.3a | 5.6a | 5.9a | 6.0a |
| Shade | TC-PF | 3.2cd | 3.6b | 4.6bc | 5.0bc | 5.5b | 5.8ab |
| Light | TC-PF | 3.6bc | 4.2ab | 5.0ab | 5.1bc | 5.9a | 6.0a |

*Mean separation within dates by LSD, 5% level.
†BB = bud break, TC = tight cluster, PF = petal fall, FS = fruit set.
‡Bloom stages ranked: 1 = tight cluster, 2 = pink, 3 = loose pink, 4 = kingbloom, 5 = full bloom, 6 = petal fall.

**TABLE 3.—Influence of Light Environment During Four Growth Periods on Fruit Set, Fruit Weight, and Carbohydrate Fractions of Potted 'Starkrimson' Delicious Fruitlets 34 Days After Petal Fall.***

| | | | 34 Days After Petal Fall | | | | | Fruit Carbohydrates (Percent of Dry Wt) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Fruitlet Wt (g) | | | | | |
| Treatment | Period† | Flowers/ Spur | Fruit/ Spur | Percent Fruit Set | Fresh | Dry | Percent Dry Matter | Sorbitol | Water Soluble Carbohydrates | Hydrolyzed Starch |
| Control | BB-FS | 4.9 | 2.7abc | 56.9ab | 17.5bc | 2.3bc | 13.0abc | 4.90b | 7.7b | 9.3b |
| Shade | BB-FS | 5.2 | 1.5c | 29.8c | 13.1bc | 1.7c | 12.7abc | 6.89a | 8.1ab | 7.0b |
| Light | BB-FS | 5.2 | 2.9ab | 55.1ab | 22.9a | 3.2a | 14.2ab | 5.41ab | 8.0ab | 14.5a |
| Shade | BB-PF | 4.8 | 1.5c | 32.6bc | 13.7bc | 1.5c | 11.1c | 5.23b | 7.9ab | 8.1b |
| Light | BB-PF | 5.0 | 2.7abc | 55.6ab | 16.6bc | 2.1bc | 12.4bc | 5.85ab | 8.3ab | 12.3a |
| Shade | TC-PF | 5.2 | 2.7abc | 51.3abc | 17.3bc | 2.2bc | 12.7abc | 5.27b | 8.0ab | 8.1b |
| Light | TC-PF | 5.0 | 2.9ab | 59.1ab | 15.5bc | 2.0bc | 13.0abc | 5.83ab | 8.8a | 9.3b |
| Shade | PF-FS | 5.1 | 1.7bc | 34.0bc | 12.1c | 1.6c | 13.4abc | 6.86a | 8.3ab | 6.9b |
| Light | PF-FS | 5.0 | 3.3a | 64.0a | 18.4ab | 2.8ab | 15.0a | 6.41ab | 8.1ab | 12.2a |

*Mean separation by LSD, 5% level.
†BB = bud break, TC = tight cluster, PF = petal fall, FS = fruit set.

Fruitlet fresh weight and dry weight 34 days APF was increased with increased light during the entire BB-FS period (Table 3). Shade during BB-FS or PF-FS reduced fruitlet fresh and dry weight compared to increased light, but not compared to controls. Fruitlet length and diameter were decreased by all shade treatments, but L/D ratio was increased (data not presented). Percent fruitlet dry matter (percent D.M.) was highest on trees of light treatments during PF-FS and BB-FS periods and lowest when shaded during BB-PF, but there was no difference in percent D.M. between any treatment and the control.

## Fruitlet Carbohydrates

Sorbitol content on a percent dry weight basis was generally increased in fruitlets from trees shaded immediately prior to sampling (BB-FS, PF-FS); however, there was no difference when trees were shaded early and then placed in ambient conditions (BB-PF, TC-PF) (Table 3). Water soluble carbohydrates were unaffected by treatment, but increasing light increased fruitlet starch, except at TC-PF. Sorbitol is the primary product of photosynthesis, the major translocated carbohydrate in apple, and a common constituent and storage compound in fruit. Differences in sorbitol could be accounted for by one of the following: 1) increase in sorbitol synthesis, 2) increase in translocation, or 3) decrease in conversion.

Shade treatments reduced light below the 30% full sun needed for photosynthesis saturation (16% full sun), thus reducing Pn (3). Since sorbitol content is related to Pn rates (5), there would be no increase in synthesis to account for sorbitol increases. Since set was reduced by shade, it may be argued that the remaining fruitlets of shaded spurs had increased "sinkness" for sorbitol. However, starch, the other predominant storage carbohydrate, was decreased in shaded fruitlets, indicating less carbohydrate being translocated to and assimilated in the fruitlets. Also, when mg sorbitol/fruit was calculated, shaded fruit had considerably less sorbitol than lighted fruit (106 vs. 146 mg/fruit, respectively). Sorbitol content was not well correlated to set ($r = -.376$) or fruits per spur ($r = -.322$), and therefore sinkness effects were not apparent.

Since sorbitol/starch ratios are higher in shaded fruits, it appears that the conversion of sorbitol to fructose via sorbitol dehydrogenase (SDH) (NAD cofactor) and subsequent conversion and utilization is reduced. Several circumstances may account for this: 1) a reduction in respiratory loss of sorbitol at low light and low temperatures; shade reduced dark respiration (3) and possibly other respiratory carbohydrate loss (*e.g.*, pho-

**TABLE 4.—Influence of Light Environment During Four Periods on Fruit Size, Dry Matter, Quality, and Seed Number of Potted 'Starkrimson' Red Delicious.***

| | | Fruit Size | | | | Fruit at Harvest | | Fruit Quality | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | Period† | Length (mm) | Diameter (mm) | Length/ Diameter | Fruit Wt (g) | Fruit Wt/Tree | Percent Dry Matter | Color‡ | Firmness (lb) | Soluble Solids (%) | Seed No. |
| Control | BB-FS | 78.5bc | 86.9 | 0.78bc | 283.6 | 511.3b | 14.4 | 1.6 | 9.6abc | 15.4 | 6.5 |
| Shade | BB-FS | 95.8a | 88.7 | 0.95a | 332.2 | 163.4b | 13.8 | 1.7 | 10.9ab | 15.0 | 6.1 |
| Light | BB-FS | 88.7ab | 89.8 | 0.89ab | 328.4 | 702.6ab | 15.7 | 1.8 | 9.0c | 15.8 | 6.2 |
| Shade | BB-PF | 88.0ab | 87.4 | 0.88ab | 308.3 | 72.2b | 13.4 | 2.1 | 10.6abc | 15.1 | 6.3 |
| Light | BB-PF | 81.6bc | 86.0 | 0.81bc | 274.4 | 1151.3a | 14.6 | 1.7 | 9.6abc | 15.2 | 6.5 |
| Shade | TC-PF | 85.5abc | 89.5 | 0.86abc | 326.8 | 596.3ab | 14.0 | 2.3 | 10.3abc | 15.0 | 5.9 |
| Light | TC-PF | 86.9abc | 90.3 | 0.87abc | 327.5 | 733.7ab | 14.7 | 2.1 | 9.5bc | 14.9 | 5.2 |
| Shade | PF-FS | 77.2c | 81.3 | 0.77c | 240.8 | 195.7b | 14.4 | 2.5 | 11.0a | 14.7 | 4.9 |
| Light | PF-FS | 82.5bc | 87.3 | 0.83bc | 288.3 | 561.9ab | 14.1 | 1.9 | 8.9c | 15.4 | 5.2 |

*Mean separation by LSD, 5% level.
†BB = bud break, TC = tight cluster, PF = petal fall, FS = fruit set.
‡Color rated by photograph standards: 1 = 100% red, 5 = 60% red. Average of two independent observations.

torespiration, etc.); 2) an inhibition of SDH-activity due to lack of cofactor or improper physiological environment for enzyme kinetics; and 3) a feed-back inhibition from conversion to fructose and/or subsequently to starch. Shaded fruitlets may have had lower rates of carbohydrate utilization and thus, although lower starch concentrations were evident, may have been metabolically saturated.

Perhaps of greater importance is the relationship between light, temperature, carbohydrate content, and fruit set (Tables 1, 3, 5). Our data and several other reports have indicated that shade reduces fruit set (8, 9, 19), but increased light did not increase set (9). Likewise, partial spur leaf defoliation (1, 10), complete defoliation, and girdling spurs (10) reduced fruit set. This evidence implicates the role of spur leaves in carbohydrate assimilation and supply necessary for fruit set and a saturation-kinetics relationship may be present.

Reducing light below 30% full sun for more than 30 days resulted in reduced set, and percent sun was significantly positively correlated to set ($r = .670$). However, temperature may also influence set (Tables 1, 3). The degree hour units >21° C were better correlated to set ($r = .822$). To the contrary, fruit set of small greenhouse grown 'Delicious' was reduced when exposed to 21° C (18). Dennis evaluated set of 'Delicious' in several orchard sites with varying environments and concluded that solar radiation in the 3 weeks before bloom and to a lesser extent during bloom was significantly correlated to set (7). Temperature was also related to set, but light accounted for more set variation than did temperature.

In our study, starch content was significantly correlated to light ($r = .883$) and 21° degree hour units ($r = .788$). Thus, starch and total extracted carbohydrates were correlated to set ($r = .702, .628$).

All of the preceding evidence disputes the contention that differences in flowering, fruit set, or cropping do not relate to limitation in carbohydrate supply (2, 14, 19). However, we do not contend that carbohydrates are solely responsible, as growth regulators are undoubtedly involved (2, 14, 19).

## Fruit at Harvest

Shade tended to reduce fruitlet length and diameter when measured 34 days APF (data not presented). A different effect was observed at harvest as fruit length and L/D ratio were increased by shade during BB-FS (Table 4). Webster and Crowe (23) also found that 'McIntosh' fruit had increased L/D ratio when shaded early in the season compared to shading later in the season or not shading. Shaw (20) observed that fruit shape was determined within 16 days after bloom and high temperatures resulted in oblate fruits. Tamura *et al.* (22) found that fruit flesh cell division was completed 10 days earlier by increasing temperatures 4° C at 1 week after bloom. Thus, fruit weight and diameter 19 days after petal fall were increased, but the effects were not evident later in the season. However, fruit shape may change between 60-100 days after petal fall, as length was negatively correlated to 5° C degree days for the entire season and not just the bloom period (24).

**TABLE 5.—Correlation Coefficients (r) of Environmental Conditions and Fruit of Young Potted 'Starkrimson' Delicious Trees.**

| Variable | Environmental Variables: Percent Full Sun | Degree Hours 10° | Degree Hours 15.5° | Degree Hours 21° | Fruit 34 Days After Petal Fall: Percent Set | Percent Dry Matter | Sorbitol | Soluble Carbohydrates | Starch | Total Carbohydrates |
|---|---|---|---|---|---|---|---|---|---|---|
| Degree Hours >10° | .501 | | | | | | | | | |
| 15.5° | .739* | .849** | | | | | | | | |
| 21° | .843** | .695* | .933** | | | | | | | |
| **Fruit Variables** | | | | | | | | | | |
| Percent Set | .670* | .657* | .698* | .822** | | | | | | |
| Percent Dry Weight 34 Days APF | .482 | .046 | –.027 | .203 | .559 | | | | | |
| Sorbitol | –.189 | –.516 | –.563 | –.560 | –.376 | .317 | | | | |
| Soluble Carbohydrates | .239 | .074 | .198 | .191 | .157 | .151 | .361 | | | |
| Starch | .883** | .287 | .582 | .788* | .702* | .528 | –.261 | –.060 | | |
| Total Carbohydrates | .872** | .155 | .454 | .667* | 628* | .644* | .036 | .104 | .954** | |
| Length | –.199 | –.689* | –.388 | –.261 | –.350 | –.211 | .129 | .131 | –.069 | –.026 |
| Diameter | .160 | –.079 | .179 | .350 | .357 | .001 | –.423 | .178 | .290 | –.191 |
| L/D Ratio | –.186 | –.692* | –.383 | –.236 | –.314 | –.177 | .108 | .149 | –.042 | –.004 |
| Weight | –.036 | –.326 | –.074 | .082 | .054 | –.114 | –.278 | .176 | .087 | .022 |
| Color | –.341 | –.116 | –.248 | –.302 | –.306 | –.087 | .207 | .417 | –.477 | –.407 |
| Firmness | –.793** | –.444 | –.630 | –.840** | –.918** | .606* | .351 | –.064 | –.844** | –.817** |
| Percent Soluble Solids | .619* | .121 | .316 | .549 | .520 | .431 | –.457 | –.499 | .839** | .708* |
| Percent Dry Matter | .900** | .448 | .558* | .640* | .513 | .533 | –.137 | .270 | .704* | .705* |
| Seed No. | .065 | .134 | .262 | .202 | –.040 | .484 | –.600* | –.665* | .225 | .021 |

| Variable | Correlation Coefficients, Fruit at Harvest: Length | Diameter | L/D Ratio | Weight | Color | Firmness | Percent Soluble Solids | Percent Dry Matter |
|---|---|---|---|---|---|---|---|---|
| **Fruit Variables** | | | | | | | | |
| Diameter | .660** | | | | | | | |
| L/D Ratio | .997** | .660** | | | | | | |
| Weight | .805** | .938** | .805** | | | | | |
| Color | .010 | –.250 | .659** | –.169 | | | | |
| Firmness | .163 | –.419 | .128 | –.303* | .468 | | | |
| Percent Soluble Solids | .078 | .396 | .098 | .204 | –.652* | –.757* | | |
| Percent Dry Matter | –.142 | .151 | –.129 | .062 | –.200 | –.433* | .535** | |
| Seed No. | .240 | .300 | .206 | .215 | –.680* | .043 | .105 | .022 |

$^{**}P$ (r) $< .01$.
$^{*}P$ (r) $< .05$.

Fruit L/D ratio was significantly but negatively correlated to 10° degree hour units (Table 5). Thus, the environmental conditions prior to bloom also influenced fruit size and shape as well as the environment in the period after bloom.

Fruit weight at harvest was not affected by treatment (Table 4). This may have been due to the fact that all clusters were thinned to a uniform one fruit per cluster at 34 days APF and trees put in a uniform condition until harvest. Fruit weight per tree was increased by the BB-PF light treatment, and tended to be reduced by shade treatments when compared to increased light treatment for the same period.

Even though there was a significant effect of light and shade on percent D.M. at 34 days APF (Table 3), there was no apparent effect at harvest (Table 4). Color was generally reduced by shade early in the season. Firmness was increased by the shade treatments at BB-FS or PF-FS compared to increased light at the same period and negatively correlated to light, 21° degree hour units, and fruit starch content (Table 5). There was no significant effect of early season environment on percent soluble solids at harvest, although soluble solids were significantly correlated to percent sun and starch content at 34 days after PF (Table 5). Seed number was unaffected by treatment and had a significant, but low, negative correlation to fruitlet sorbitol, soluble carbohydrates, and fruit color.

Since high temperatures (21° dhu) were significantly correlated to the light treatments (Table 5), separating variable response due to either condition individually is difficult and both light and temperature may affect response. Therefore, stepwise multiple regression was used to account for variation in responses (Table 6). Only those responses are presented for which multiple regression was significant and more variability was explained by the combination of light and temperature than accounted for separately.

Fruitlet starch and total extracted carbohydrate were significantly correlated to percent sun (r = .88, .87, and R 2 = .78, .76, respectively), but not to degree hour units >10° C. However, fruitlet starch and total carbohydrate contents were increased with combined increasing light and decreasing 10° degree hour units (Table 6). Some 82% and 87% of the variation of starch and total carbohydrate content were explained by the combination of terms, more than either factor accounted for individually, and slopes (coefficient) of percent sun term were larger than that for the temperature term. Likewise, percent D.M. at harvest was increased with increasing light early in the season and decreasing hours of high temperature, accounting for 86% of the variation. Again, the slope of the light term was greater than that for temperature.

## Spur Growth

Spur diameter was reduced on spurs in shade treatments during BB-FS (Table 7). There was no treatment effect on spur length. On spurs which formed bourse shoots, light treatments did not affect shoot diameter or length. Spur leaf number (2 weeks after harvest) was not affected by light conditions early in the season. This was expected because initiation and differentiation of spur tissues would have occurred in the season prior to treatments. Spur leaf area was not influenced by treatment, although spur leaves from shade treatments averaged 109.6 $cm^2$ and those of light treatments averaged 97.0 $cm^2$. Specific leaf weight (SLW) is a function of light regime in which leaves develop and leaves will readjust to different light environments (3). Therefore, treatment effect on SLW was not present 140 days after treatments were discontinued.

## Return Bloom the Following Year

When spur clusters were counted the next season at the pink stage, there were no significant differences in flower cluster numbers, flower numbers, or leaf numbers due to treatment the previous spring (Table 8). However, several trends are worthy of note.

Total flower clusters per tree were increased 22% on trees of previous season increased light treatments, compared to controls, and decreased 8% on trees of shade treatments. Flowers per spur were generally higher on trees which were shaded the previous spring compared to those which were lighted, with the exception of trees shaded for the BB-FS period. This was probably a result that shade for the entire BB-FS period (75 days) inhibited flower initiation, which occurs during that period. Trees shaded only for a portion of that period (BB-PF, TC-PF, PF-FS) did not inhibit flower initiation, but because of reduced set by shade (Table 2) had increased flower initiation. The same general trend was observed for flowers per cluster. No trend was observed for leaves per spur, per cluster, or per flower.

**TABLE 6.—Multiple Regression Equation of Fruit Variables Using Percent Full Sun and Degree Hours as Predictors.**

| | Regression Coefficients | | | | | |
|---|---|---|---|---|---|---|
| Fruit Variable | Intercept | Percent Full Sun | 10° | 21° | $R^2$ | Prob > (f) |
| Starch | 26.22 | .1570 | –.0164 | | 81.8 | .007 |
| Total Carbohydrate | 53.14 | .1637 | –.0289 | | 86.8 | .002 |
| Firmness | 12.42 | –.0139 | | .0092 | 73.1 | .019 |
| Percent Dry Matter at Harvest | 13.74 | .0487 | | –.0053 | 86.0 | .003 |

**TABLE 7.—Influence of Light Environment During Four Growth Periods on Leaf Development and Spur Growth of Potted 'Starkrimson' Red Delicious Tree Spurs.***

| | | 1983 Spur | | 1983 Bourse | | Spur Leaves | | | Bourse Shoot Leaves | | | Total Leaves | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | Period† | Diameter (mm) | Length (mm) | Diameter (mm) | Length (mm) | No. | Area (cm$^2$) | SLW (mgcm$^{-2}$) | No. | Area (cm$^2$) | SLW (mgcm$^{-2}$) | No. | Area (cm$^2$) |
| Control | BB-FS | 7.7a | 17.0 | 4.8 | 18.8 | 8.0 | 112.9 | 8.2abc | 6.1ab | 167.0 | 7.7bc | 15.2ab | 307.6 |
| Shade | BB-FS | 6.1b | 17.9 | 3.2 | 5.3 | 7.2 | 120.2 | 6.1c | 2.8b | 65.3 | 5.9c | 9.4b | 175.6 |
| Light | BB-FS | 8.2a | 20.5 | 5.0 | 18.8 | 6.3 | 125.0 | 8.1abc | 12.3a | 299.4 | 9.5a | 18.0a | 394.6 |
| Shade | BB-PF | 7.3ab | 18.6 | 4.8 | 13.4 | 8.0 | 119.8 | 8.2abc | 7.4ab | 213.9 | 8.0abc | 9.0b | 138.5 |
| Light | BB-PF | 7.7a | 20.1 | 4.2 | 12.3 | 6.5 | 89.8 | 9.5a | 8.0ab | 182.7 | 8.3ab | 13.7ab | 249.5 |
| Shade | TC-PF | 7.9a | 20.8 | 5.1 | 18.7 | 4.9 | 94.2 | 8.2abc | 11.8a | 350.7 | 7.9bc | 15.1ab | 401.9 |
| Light | TC-PF | 7.5ab | 16.5 | 4.4 | 10.1 | 5.1 | 74.5 | 8.8ab | 4.3b | 98.9 | 7.4bc | 9.4b | 173.4 |
| Shade | PF-FS | 6.2b | 19.9 | 4.1 | 13.4 | 6.7 | 104.1 | 7.2bc | 7.8ab | 259.9 | 7.4bc | 14.5ab | 364.0 |
| Light | PF-FS | 7.3ab | 20.2 | 4.6 | 16.1 | 6.2 | 100.1 | 8.4ab | 10.2ab | 229.8 | 8.1ab | 16.4ab | 329.9 |

*Mean separation by LSD, 5% level.
†BB = bud break, TC = tight cluster, PF = petal fall, FS = fruit set.

**TABLE 8.—Influence of Light Environment During Four Growth Periods on Return Bloom the Following Year of 'Starkrimson' Delicious Apple Trees.**

| | | 1984 Bloom | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1983 Treatment | Period† | Flower Clusters per Tree | Flower Clusters per Spur | Flowers per Spur | Flowers per Cluster | Leaves per Spur | Leaves per Cluster | Leaves per Flower |
| Control | BB-FS | 15.6 | 1.6 | 4.4 | 2.8 | 9.9 | 6.1 | 2.0 |
| Shade | BB-FS | 13.1 | 1.4 | 5.0 | 2.9 | 9.3 | 6.3 | 1.5 |
| Light | BB-FS | 22.3 | 2.1 | 8.3 | 3.7 | 12.5 | 6.1 | 1.5 |
| Shade | BB-PF | 12.6 | 2.1 | 8.6 | 4.4 | 12.5 | 6.5 | 1.5 |
| Light | BB-PF | 17.3 | 1.7 | 7.4 | 4.4 | 12.0 | 7.3 | 1.7 |
| Shade | TC-PF | 17.3 | 1.8 | 7.5 | 4.4 | 11.3 | 6.8 | 1.5 |
| Light | TC-PF | 19.0 | 1.2 | 4.9 | 4.1 | 8.2 | 6.9 | 1.6 |
| Shade | PF-FS | 14.3 | 2.1 | 7.0 | 3.4 | 15.6 | 7.1 | 2.3 |
| Light | PF-FS | 17.5 | 1.6 | 3.9 | 2.5 | 9.6 | 6.1 | 2.0 |
| | | N.S.* | N.S. | N.S. | N.S. | N.S. | N.S. | N.S. |

*N.S. = No significance by LSD, 5% level.
†BB = bud break, TC = tight cluster, PF = petal fall, FS = fruit set (1983 treatment).

## CONCLUSIONS

The light and temperature environment early in the season, during spur development, bloom, and fruit set periods, does affect the performance of a fruiting spur. Because temperature was related to the light level, it was not possible to separate the effects of light and temperature in this study. Nonetheless, the total environment during the early period affected set and early fruit development and the effects were still apparent at harvest.

Shade delayed bloom and resulted in smaller fruits with less percent dry matter content at the end of the cell division period. Carbohydrate content of fruits was affected by light treatment and was related to fruit quality at harvest.

In an attempt to select "critical periods" during the budbreak to fruit set period, the following deductions from our data may be made. The least effect for all variable responses resulted from light or shade treatment during tight cluster to petal fall period. Two factors may account for this: 1) the tight cluster to petal fall was the shortest treatment period (21 days) with the least increase or decrease from ambient light and temperature means; and 2) this period was after spur leaves were mature (20 days old) and autotrophic, before bourse shoots were competing with fruitlets, and at a time of low assimilate or metabolite demand.

Light during the petal fall to fruit set period appears to be most critical for fruit set. However, if light was limiting early, set was also reduced. Starch and total carbohydrate contents of fruitlets were related to fruit set and may be limiting.

The environment during budbreak to petal fall had the greatest effect on fruit size, shape, and percent dry matter. The environment during PF-FS had an effect on fruit quality, color, firmness, percent soluble solids, and seed number.

Therefore, the environment early in the season is critical to quality fruit production. Although the environment is difficult to control, orchard managers can minimize light limitations by proper pruning and maintaining a large spur leaf area.

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# Evaluation of Alternate Row Middle (ARM) Spraying for Apple Orchards[1]

FRANKLIN R. HALL[2]

## INTRODUCTION

Hall (1) observed that although azinphosmethyl was applied at the same rate per 100 gal., the grams of active ingredient actually directed towards different sized apple trees by fruit researchers varied by as much as 15-fold. Control of pests was the same regardless of this difference in delivery. Clearly, the relationships between dosage applied per target area and actual toxicity to various pests needs additional study. Such research is even more relevant since low volume and alternate row spraying techniques are offered as methodologies enhancing the integrated pest management (IPM) approach to pest control in orchards.

The alternate row middle (ARM) technique is not new to most orchardists. The objectives of ARM methodology have been to reduce costs of labor, chemicals, and fuel, and to cover orchard plantings twice as fast as conventional (CONV) every row methods. Sprays are applied in the CONV manner from both sides of *each* tree row, whereas ARM sprays are applied from only one side of the row, *alternating* between odd and even-numbered row middles with each succeeding spray treatment. Thus, a 14-day spray interval in the CONV system may be the standard, but ARM methods require every other row spraying at 7-10 day intervals. Thus, although every other row middle does not receive direct sprays, the *frequency* of application is *increased* so that a fresh deposit of pesticide is received more often than under CONV systems.

Apple dwarfing rootstocks have resulted in smaller, more dense plantings which should make the use of small, low-volume PTO sprayers with less air volume (cfm) a practical reality for ARM techniques. However, little data are available showing the potential for these sprayers in ARM systems.

Some researchers (2) have suggested that travel speeds of more than 2 mph are unsuitable for ARM programs, whereas more recently others (3) recommended that travel speeds should not exceed 3 mph. Tree fruit recommendations of New York (4), Virginia (5), Pennsylvania (6), and others (2) all cautioned that sprayers with less than 90,000 cfm are not likely to be successful in ARM programs unless trees are less than 12 ft high.

This article reports a 4-year evaluation of the cost effectiveness of a smaller sprayer in a moderately dwarfing apple orchard.

## METHODS AND MATERIALS

The orchard under study was an apple cultivar planting at the OARDC Mahoning County Farm at Canfield. The purpose of this planting, set in 1964, was to evaluate the yield and quality of various rootstock/cultivar combinations. Tree planting distances were 22.5 ft, with 25 ft and 30 ft between tree rows and an average height of ca. 15 ft.

The equipment used to spray this and other orchards at the branch was an engine-driven Myers A36, capable of producing ca. 35,000 cfm. The sprayer with one exception was used at 1.9 mph in all treatments and was calibrated to deliver ca. 110-120 GPA (in a 3X concentration). In 1980, an additional conventional treatment was applied at 3.9 mph (HS CONV). Treatments evaluated included the ARM method at 7-day intervals (2 years) and 10-14 day intervals (2 years) compared to a CONV every row pattern of spraying at 14-day intervals.

Conventional spray techniques were utilized in all treatments through the bloom period of growth. Treatments in both blocks (CONV and ARM) were initiated beginning at petal fall in each year of the study and continued until crop protection measures were no longer required (usually August). Records were kept on the number of sprays used, pest control efficiency, as well as yield and quality at harvest. A third treatment was added in the last year of testing whereby the CONV at 3.9 mph was also compared to CONV and ARM at 1.9 mph.

Approximately 110-120 GPA were delivered in the CONV block, whereas ca. 60 GPA per half spray were delivered in the ARM block. Table 1 shows the pesticides and rates.

**TABLE 1.—Pesticides and Rates.***

| Stage | Materials and | lb per 100 gal† |
|---|---|---|
| PF | Captan 50 WP | 2 |
| | Karathane 35 WP | 1/2 |
| | Guthion 50 WP | 5/8 |
| 1C | Guthion 50 WP | 5/8 |
| 2C | Captan 50 WP | 1 1/2 |
| | Karathane 35 WP | 1/2 |
| | Guthion 50 WP | 1/2 |
| 3C | Captan 50 WP | 1 1/2 |
| | Guthion 50 WP | 1/2 |
| 4C | Captan 50 WP | 1 |
| | Imidan 50 WP | 1 |
| 5C | Imidan 50 WP | 1 |
| 6C | Imidan 50 WP plus | |
| | Plictran 50 WP | 1/2 |
| 7C | Imidan 50 WP plus | 1/2 |
| | Plictran 50 WP | 1/2 if needed |

*All pesticides delivered in a 3x concentration at ca.110-120 GPA.

†Calcium chloride at 2 lb/100 gal added for a minimum of 3-4 sprays beginning at PF.

[1]Thanks are extended to John Gregory and Clifford Morrison (Manager, Mahoning County Farm) for technical assistance during the tenure of this project.

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cides and rates utilized in the study. The historical objective of this orchard was one directed towards horticultural interests. The block was not in an IPM program and full rates of pesticides were the normal pattern, with treatments made for control of European red mite, *Panonychus ulmi* Koch (ERM), as bronzing appeared within the orchard.

## RESULTS

### 1977

Table 2 shows only slight differences between treatments for the apple aphid, *Aphis pomi* DeGeer. The major differences probably are a result of pruning differences and the growth characteristics of cultivars. At

**TABLE 2.—Evaluation of CONV vs. ARM Spraying on Apples, 1977.**

| Cultivar† | Av. No. Apple Aphid Infested Terminals/Tree* CONV | ARM |
|---|---|---|
| Golden Delicious | 0.8 | 5.0 |
| Melrose | 24.2 | 7.6 |
| Holiday | 4.2 | 7.4 |
| Red King Delicious | 5.6 | 10.0 |
| Chelan Red Delicious | 19.4 | 10.0 |

*All counts made 7/14/77.
†Five trees/cultivar.

| Block | Cultivar | Total lb Fruit Evaluated | Percent Fruit Damaged at Harvest PC* | CM* | RBLR* | Other | Percent Insect Damage Free |
|---|---|---|---|---|---|---|---|
| ARM | Golden Delicious | 1406 | 0.7 | 0.5 | 0.5 | 0.1 | 98.2 |
| | Melrose | 578 | 3.6 | 0 | 1.2 | 0.5 | 94.7 |
| | Red King Delicious | 299 | 1.7 | 0.3 | 0.3 | 0.7 | 97.0 |
| | Chelan Red Delicious | 300 | 0 | 0 | 0.3 | 0.3 | 99.4 |
| | Holiday | 473 | 0.2 | 0 | 0.6 | 0.8 | 99.2 |
| | Average | 611 | 1.24 | 0.16 | 0.58 | 0.48 | 97.7 |
| CONV | Golden Delicious | 1804 | 0.3 | 0.06 | 0.4 | 0.9 | 98.3 |
| | Melrose | 799 | 4.3 | 0.4 | 0.1 | 0.6 | 94.6 |
| | Red King Delicious | 630 | 0 | 0 | 0 | 0.2 | 99.8 |
| | Chelan Red Delicious | 353 | 0.8 | 0 | 0 | 0.8 | 99.2 |
| | Holiday | 689 | 0 | 0.1 | 0.3 | 1.0 | 98.6 |
| | Average | 855 | 1.08 | 0.11 | 0.16 | 0.70 | 98.1 |

*PC = plum curculio, CM = codling moth, RBLR = redbanded leafroller.

**TABLE 3.—Evaluation of CONV vs. ARM Spraying on Apples, 1978.**

| | Av. No. Infested Terminals/Tree | | | |
|---|---|---|---|---|
| | CONV | | ARM | |
| Cultivar* | Apple Aphids | Woolly Aphids | Apple Aphids | Woolly Aphids |
| Golden Delicious | 12.2 | 1.6 | 5.0 | 0.6 |
| Melrose | 19.5 | 0.8 | 13.8 | 0.8 |
| Holiday | 12.4 | 1.8 | 18.8 | 5.8 |
| Red King Delicious | 1.8 | 1.2 | 19.6 | 2.8 |
| Chelan Red Delicious | 7.0 | 7.4 | 19.6 | 5.0 |

*Five trees/cultivar, with 10 terminals per tree examined.

| Cultivar | Block | Total lb Fruit Evaluated | Percent Fruit Damaged at Harvest PC* | CM* | RBLR* | Other | Scab | Rot | Percent Insect Damage Free |
|---|---|---|---|---|---|---|---|---|---|
| Chelan Red | ARM | 1226 | 0.0 | 0.0 | 0.2 | 0.8 | 0.2 | 2.8 | 95.9 |
| Delicious | CONV | 1277 | 0.0 | 0.0 | 0.0 | 0.8 | 0.2 | 3.7 | 95.5 |

*PC = plum curculio, CM = codling moth, RBLR = redbanded leafroller.

harvest, both programs controlled insects and the overall percent damage-free fruit data show no difference between CONV and ARM treatments in 1977.

## 1978

Sampling data for apple aphids in 1978 showed that Red King Delicious had significantly more aphids/tree in the ARM block than in CONV treatments (Table 3). Chelan Red Delicious also had a similar trend, but Golden Delicious showed the reverse trend. Woolly apple aphids, *Eriosoma lanigerum* (Hausmann), were higher in two cultivars in the ARM block but there did not seem to be a significant trend. At harvest, there were no differences between treatments with the Chelan Red Delicious cultivar.

## 1979

In 1979, the unsprayed one-third acre block showed severe damage by apple scab, *Venturia inequalis* (Cke) Wint., in both cultivars (Table 4) in the June and July evaluations. The fruit and foliar scab both increased to 100% infection levels in July. The ARM block had slightly higher fruit scab with both cultivars in July. The disease, frogeye leaf spot, *Physalospora obtusa,* was about the same in both ARM and CONV. With Holiday, there was a significant reduction in both plots vs. that in the unsprayed plot.

Control of plum curculio, *Conotrachelus nenuphar* (Herbst), in 1979 under heavy pressure showed only slight increases in damage in the ARM plots (Table 5). Green fruitworm, *Lithophane antennata* (Walker), was the same in both treatments, while woolly apple aphids tended to be higher in ARM plots and the data on apple aphids were mixed. In a pre-harvest evaluation of dropped fruit, there was a slight tendency for apple damage by both insects and apple scab to be higher in the ARM plots. All dropped fruit (100%) in the unsprayed plots were damaged by either plum curculio, codling moth, *Cydia pomonella* (L.), or apple scab.

The harvest evaluation of treated plots (Table 6)

**TABLE 4.—Evaluation of CONV vs. ARM Spraying on Apples: Disease Control, 1979.**

| | | 6/79 | | | | 7/79 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Percent Damaged | | | Av. Fireblight | Percent Damaged | | | |
| Cultivar | Block | Fruit Scab | Foliar Scab | Frog Eye | Terminals per Tree* | Fruit Scab | Foliar Scab | Frog Eye | Fireblight |
| Chelan Red Delicious | ARM | 3.2 | 4.1 | 0 | 5.0 | 3.5 | 2.9 | 6.1 | — |
| | CONV | 2.2 | 4.6 | 22.9 | 5.4 | 0 | 1.0 | 6.5 | — |
| | Unspr | 89.1 | 47.8 | 0 | — | 100 | 100 | 0.5 | — |
| Holiday | ARM | 3.3 | 2.4 | 9.6 | 11.5 | 4.5 | 13.6 | 2.5 | — |
| | CONV | 1.8 | 2.1 | 1.2 | — | 2.0 | 1.9 | 3.0 | — |
| | Unspr | 89.8 | 94.5 | 96.0 | — | 100 | 93.3 | 50.9 | — |

*Fruit scab and fireblight counts based on 2 min/tree.
†Foliar scab and frog eye leaf spot based on no. of leaves infected on 10 terminals/tree.

**TABLE 5.—Evaluation of CONV vs. ARM Spraying on Apples: Insect Control and Harvest Data, 1979.**

| | | Percent Fruit Damage* | | Av. No./Terminal† | |
|---|---|---|---|---|---|
| | | 6/79 | | 7/79 | |
| Cultivar | Block | PC | Fruitworm | Woolly Aphids | Apple Aphids |
| Chelan Red Delicious | ARM | 2.2 | 0.3 | 81 | 8 |
| | CONV | 1.3 | 0.2 | 0 | 23 |
| | Unspr | 78.7 | 4.5 | 0 | 15 |
| Holiday | ARM | 3.3 | — | 24 | 24 |
| | CONV | 1.0 | — | 0 | 0 |
| | Unspr | 72.7 | 2.0 | 0 | 8 |

*Plum curculio and fruitworm injured fruits based on fruit examination on trees: 2 min/tree, 5-8 trees/cultivar.
†Aphid counts based on 2 min/tree, 5-8 trees per cultivar.

| | | | Percent Fruit Damaged—Drop Evaluation* | | | | | |
|---|---|---|---|---|---|---|---|---|
| Cultivar | Block | Total Fruit | PC† | CM† | RBLR† | LAW† | Other Insects | Scab |
| Holiday | ARM | 519 | 4.2 | 3.1 | 2.9 | 0.39 | 6.9 | 4.1 |
| | CONV | 511 | 0.6 | 0.6 | 0.4 | 0 | 2.5 | 0.8 |
| | Unspr | 50 | 50.0 | 10.0 | 0 | 0 | 16.0 | 100.0 |

*All dropped apples collected and rated 8/21/79.
†PC = plum curculio, CM = codling moth, RBLR = redbanded leafroller, LAW = lesser apple worm.

**TABLE 6.—Evaluation of CONV vs. ARM Spraying on Apples: Harvest, 1979.**

| Cultivar | Block | Bu/Acre | Percent Fruit Damage: Apple Scab | Percent Fruit Damage: Total Insect | Percent Fruit Damage: Other | Bu of Undamaged Fruit/Acre |
|---|---|---|---|---|---|---|
| Chelan Red Delicious | ARM | 196 | 7.3 | 5.6 | 0.6 | 172 |
| | CONV | 285 | 2.70 | 2.38 | 1.90 | 265 |
| | Unspr | 4 | 100 | 64.8 | 5.5 | 0 |
| Holiday | ARM | 959 | 15.5 | 12.7 | 5.7 | 674 |
| | CONV | 905 | 2.0 | 0 | 5.1 | 841 |
| | Unspr | 14 | 100 | 52.6 | 3.2 | 0 |

**TABLE 7.—Evaluation of CONV vs. ARM Spraying on Apples: 1980.***

| Treatment | Percent Terminals with Apple Scab† 7/15 | Percent Fruit with Plum Curculio† 7/15 | Av. No. Mites/Leaf on 7/15‡: ERM†† | Av. No. Mites/Leaf on 7/15‡: TSSM†† | Av. No. WAA†† Colonies/Tree on 7/19: Chelan Red Delicious | Av. No. WAA†† Colonies/Tree on 7/19: Holiday |
|---|---|---|---|---|---|---|
| CONV | 2.0 b** | 3.4 c | 9.94 b | 0.60 a | 55.3 a | 1.0 b |
| HS CONV | 3.5 b | 1.5 c | 58.9 a | 0.38 a | 36.8 b | 3.3 b |
| ARM | 7.5 b | 10.0 b | 0.61 c | 0.02 b | 26.5 b | 26.3 a |
| Unspr | 73.4 a | 17.0 a | 0.78 c | 0.01 b | 8.5 c | 2.0 b |

*HS CONV = higher travel speed CONV (3.9 mph).
†Based on 4-5 trees per cultivar, Chelan Red Delicious and Holiday.
‡Sampled at 25 leaves/tree based on 4-5 trees per cultivar.
**In each column, means followed by same letter are not significantly different at .05 level (DNMRT).
††WAA = woolly apple aphid, ERM = European red mite, TSSM = twospotted spider mite.

showed a slight increase in insect and disease damage in Chelan Red Delicious ARM plots and higher levels of damage with the Holiday cultivar in ARM plots. Both insect and disease damage potentials were very high in 1979.

### 1980

In 1980, the CONV had an additional area treated at 3.9 mph (HS CONV). The result of this higher travel speed is dramatically shown with data on European red mite (Table 7). In general, the higher travel speed did not significantly change control of either foliar apple scab or plum curculio; however, ratings of both of these pests in ARM plots were higher than CONV blocks and significantly reduced from unsprayed plots. Woolly apple aphid data were mixed; the most severe rating was CONV with Chelan Red Delicious, and in Holiday the ARM plots had higher aphid counts.

**TABLE 8.—Comparison of Apple Yields on CONV and ARM of Plots: 1976-1980.**

| Year | Treatment | Av. lb Fruit/Tree: Chelan Red Delicious | Av. lb Fruit/Tree: Holiday |
|---|---|---|---|
| 1976 | CONV | 183 | 514 |
| | ARM | 164 | 486 |
| 1977 | CONV | 38 | 117 |
| | ARM | 23 | 141 |
| 1978 | CONV | 254 | 380 |
| | ARM | 284 | 334 |
| | Unspr | 297 | 235 |
| 1979 | CONV | 162 | 519 |
| | ARM | 117 | 574 |
| | Unspr | 2 | 7 |
| 1980 | CONV | 567 | 830 |
| | HS CONV | 775 | 462 |
| | ARM | 427 | 705 |
| | Unspr | 155 | 9 |

### Yields

Yield data varied from year to year (Table 8) and also by cultivar. In summary, of the 5 years of yield data recorded, under CONV and ARM tests yields were about the same in 4 of 5 years with Holiday. The Chelan Red Delicious was more erratic in yields and favored the CONV in 4 of 5 years. However, in 1980, the HS CONV plot had 37% higher yields than the CONV. In each year, all test plots had significantly higher fruit yields than the unsprayed trees.

## DISCUSSION

### Cost Effectiveness

Table 9 presents data on the number of full cover sprays in CONV and the full-spray equivalents in ARM plots. The reduction in "times across the orchard" varied from a low of 14% in 1978 to 43% reduction in 1979. This reduction, for example, means that 3.5 fewer trips were made on that block. A cost projection reveals that at \$30/acre for labor/sprayer and an average cover spray tank mix at \$9/acre, a total seasonal savings in labor, equipment, and pesticides for the ARM vs. CONV technique is projected to be ca. \$140/acre. If ARM yields are *not* affected, an increase of ca. 2% in pest damage (as noted in previous tables) based on a 600 bu/acre yield projects to a grade reduction of ca. 12 bu/acre. With a grade reduction cost of ca. $5/bu (based on direct sales marketing), this translates to a decrease in revenue of ca. $60/acre. Consequently, there is still a net gain in savings with ARM technology.

It is not known whether the yield reduction in ARM plots (Red Delicious) depicted in Table 8 in 1979 was real or an artifact. However, if yields of this magnitude are the norm, then the 1 to 2 bu/tree reduction in yield, based on 80 trees/acre, means a net loss of from $800 to $1600/acre (fancy quality fruit, direct sales market). In this case, the cost savings by ARM would not result in a gain in profit.

There are other benefits from an ARM strategy. A reduction in pesticide load in the orchard environment can mean that IPM strategies are enhanced by yielding higher predator survival potentials (6). As depicted, for example, in Table 10 for 1978 and 1979, the reductions in pounds of AI pesticide/acre are real and meaningful reductions. Consequently, such objectives would be long-term rather than short-term gains. Growers, however, are risk-aversive and are traditionally less enchanted about such long-term objectives. Instead, they prefer to deal (rather pragmatically) with real-world, short-term gains.

## SUMMARY AND CONCLUSIONS

These tests were severe in that *no adjustments* within each year were made according to either pest pressure or weather abnormalities, etc. The sprayer's capacity to deposit sprays at 30 ft from some of the thicker cultivars was minimal but sufficient to maintain pest control. Cost savings from an ARM protocol are meaningful *if* there are no changes in either yield or quality. This means that there is a potential for management error and so there are risks in adopting this technique. With *management precision,* these are minimal and the enhancement of IPM strategies to maximize mite predator survival would be of value, particularly in 1983, where several sprays of miticide alone accounted for expenditures as high as $50-$75/acre.

Under an ARM program, the grower is on the cutting edge; he must be able to *recognize* the need for adjustments following a *proper identification* of the problem. Adequate *planning* is absolutely essential. ARM protocols are *not as easy* as routine 2-week scheduling of plant protection measures. There are *increased risks* from a variety of sources and this alone can act as a *major constraint* to ARM being an acceptable practice for many growers.

In this project, over a 5-year period, it has been demonstrated that a low-volume, moderately sized sprayer can deliver pesticides in adequate levels to well-pruned apple trees, 15-16 ft in height, spaced 25-30 ft in rows, without significant loss of pest control. It is also clear that such programs must be closely monitored by orchard managers in order to adjust for specific environmental and pest variations as needs develop within and between each season.

**TABLE 9.—Number of Full Sprays on Apples, 1977-1979.***

| | | ARM | | |
|---|---|---|---|---|
| Year | CONV | 1/2 Spray | Full Spray Equivalents | Percent Change |
| 1977 | 9 | 13 | 6.5 | 27.8 |
| 1978 | 7 | 12 | 6 | 14.3 |
| 1979 | 8 | 9 | 4.5 | 43.7 |

*Petal fall through 6th cover.

**TABLE 10.—Comparison of CONV vs. ARM Pesticide Usage on Apple, 1977-1978.**

| | Total lb AI/Acre | | |
|---|---|---|---|
| Material | CONV | ARM | Percent Reduction |
| | 1977 | | |
| Captan 50 WP | 21.3 | 7.5 | 64.8 |
| Guthion 50 WP | 4.0 | 1.6 | 60.0 |
| Imidan 50 WP | 3.6 | 3.6 | 0 |
| Karathane 35 WP | 1.8 | 0.95 | 47.8 |
| Plictran 50 WP | 0.9 | 0.9 | 0 |
| | 1978 | | |
| Captan 50 WP | 15.0 | 6.8 | 54.7 |
| Guthion 50 WP | 3.4 | 1.0 | 70.3 |
| Imidan 50 WP | 4.5 | 3.6 | 20.0 |
| Karathane 35 WP | 1.6 | 0.47 | 70.6 |
| Plictran 50 WP | 0.8 | 0.45 | 43.8 |

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# Penetration of an Apple Tree Canopy by Orchard-Sprayer Air Jets[1]

R. D. FOX,[2] D. L. REICHARD,[2] R. D. BRAZEE,[3] and F. R. HALL[4]

## INTRODUCTION

When orchard air sprayers apply pest control agents to fruit trees, the air jet must transport the spray droplets to all sectors of the tree. To reach the interior of the canopy, jets must penetrate the thickest part of the foliage and retain sufficient velocity to transport droplets to target leaves. Air jet penetration is affected by tree shape, foliage density, and rigidity. To achieve a uniform distribution of pest control agents on all parts of a tree, it is necessary to understand how tree canopies interact with sprayer jets.

Randall (6) found that jet velocities of 27 mph were necessary to penetrate Cox apple tree canopies. Reichard *et al.* (7) measured air velocities within trees produced by moving sprayers. They found that trees had considerable influence on air velocities delivered by sprayers and that velocities within canopies were more erratic than in open flow. In general, velocities were lower within trees, except for a small proportion of the locations where velocities were higher than at similar locations in unobstructed flow.

Brazee *et al.* (1) developed a computer model for sprayer jets and extended it (3) to account for jet deflection by crosswinds and sprayer travel. It may be possible to extend the model further to include dissipation of the jet by a tree canopy.

The objectives of this study were to measure the ability of a sprayer jet to penetrate the canopy, and thereby promote theoretical advances in the computer model to account for within-canopy attenuation of the jet. Air velocities were measured at selected points in a tree canopy to quantify the interactive effects of air volume flow rate, outlet air velocity, sprayer travel speed, and canopy resistance on the jet velocity distribution.

## METHODS AND MATERIALS

Canopy penetration by orchard sprayer air jets was estimated by measuring air velocities induced by each of two sprayers at nine sites within a semi-dwarf Melrose apple tree (Fig. 1). The tree was about 9 ft in height and 11 ft in diameter, although trees within the row overlapped each other. Each series of experiments was conducted during the same day when wind speeds were less than 4.5 mph.

The sprayers used were Myers A32 (No. 1) and Myers A36 (No. 2), which were PTO and engine-driven, respectively. Sprayer dimensions and characteristics are listed in Table 1. Sprayer outlet-air-velocities listed are the maximum air velocities measured on a traverse across the outlet at a distance of one-half inch from the outlet.

In experiments on the effects of air velocity on tree penetration, five passes of the experimental site at 3 mph were made with sprayer No. 1 for each of four PTO speeds, 250, 350, 450, and 550 rpm. Fan speed was 4.55 times the PTO speed.

In experiments on the effects of air volume flow rate and sprayer travel speed, sprayer Nos. 1 (PTO at 550 rpm) and 2 were taken past the experimental site at 2, 3, and 4 mph. Air velocities were measured and analyzed on-line for each of six passes. Each measurement period began when the sprayer outlet was 8.2 ft from the sensor and continued until the outlet was 16.4 ft past the sensor. Start and stop signals for the air velocity measurements were triggered as a tractor wheel passed over a treadle switch.

The centerlines of all sprayers were maintained at a 10 ft horizontal distance from the tree centerline. Because sprayer outlet radii were not equal, the outlet for sprayer No. 2 was 2 inches nearer the tree than the outlet of sprayer No. 1.

Air velocities were measured with constant temperature hot-film (CTHF) sensors mounted with their longitudinal axes in the vertical plane at sites shown in Figure 1. All sensors were oriented with their longitudinal axes perpendicular to a radius from the sensor to the sprayer-fan centerline. Thus, air velocities were measured in a plane determined by the sprayer-fan centerline and the line passing through the sensor site and intersecting the sprayer-fan centerline. For each of nine anemometers, and for each pass, 10 mean velocities per

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TABLE 1.—Sprayer Characteristics.

| Sprayer No. | Outlet Radius, inches | Outlet Width, inches | Outlet Air Velocity, mph |
|---|---|---|---|
| 1 (with PTO speed of 550 rpm) | 20.5 | 5.2 | 66 |
| 2 | 22.0 | 5.5 | 100 |

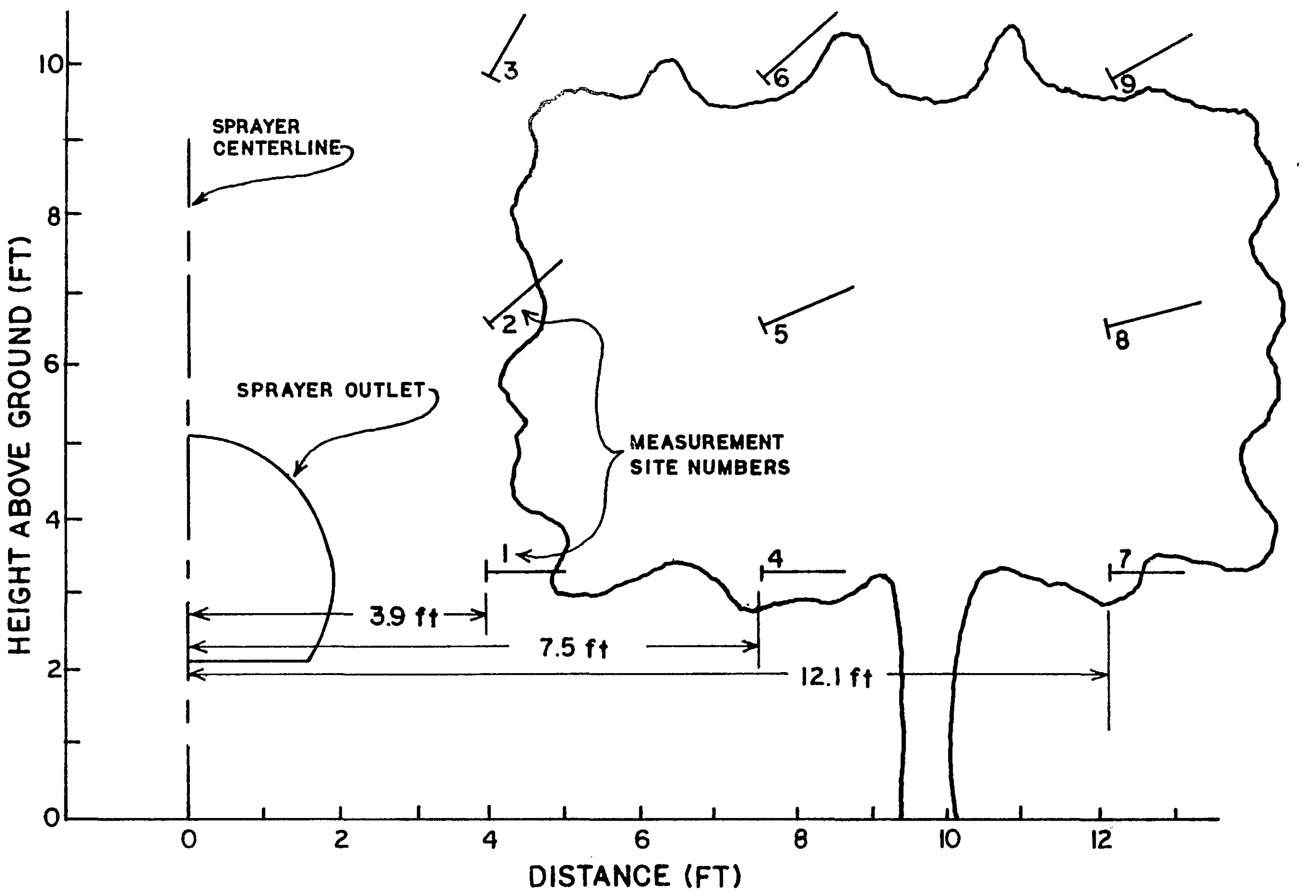


FIG. 1.—Schematic drawing of anemometer sensor sites in semidwarf apple tree.

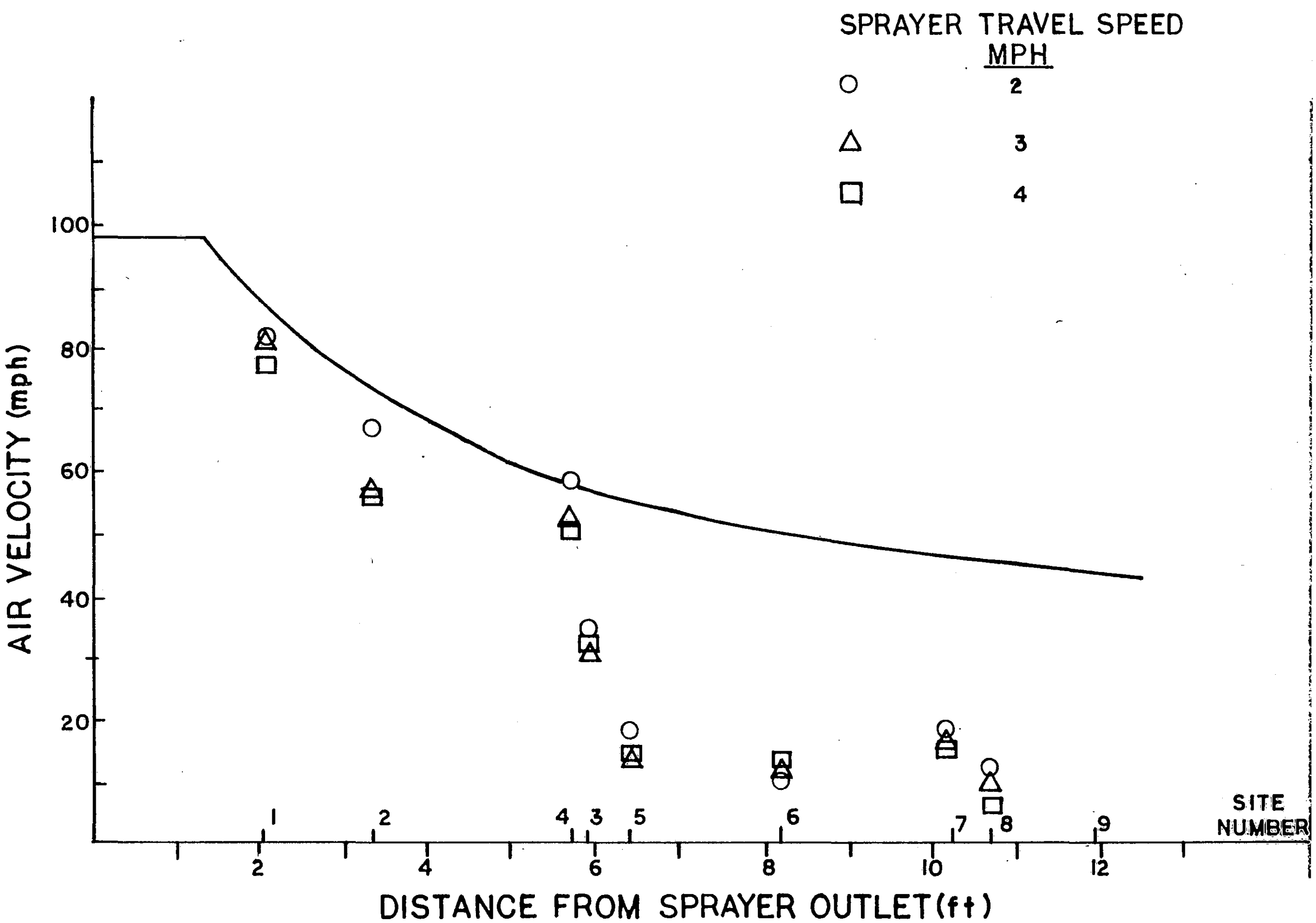


FIG. 2.—Air velocities in tree from sprayer No. 2 at three travel speeds. Solid line is air velocity predicted by a computer model for a stationary sprayer.

second were calculated from 200 samples per second. In addition to the mean velocities, we also recorded the largest single sample velocity during each pass and the sprayer location at the time of the largest velocity. For some experiments, the CTHF sensor at site 9 was not operational, so no data were available for that location.

## RESULTS

### Effect of Sprayer Travel Speed

Sprayer No. 2 traveled past the tree at 2, 3, and 4 mph. Figure 2 is a plot of mean velocities from six passes at each travel speed. The solid line in Fig. 2 represents jet air velocities which were predicted by a computer model of this air sprayer if we assumed the sprayer was stationary with no obstruction (4). At every measurement point except one, measured velocities were 10-15% greater when the sprayer was traveling at 2 mph than when it was traveling at 3 to 4 mph. At most points the decrease in air velocity due to a change in travel speed from 3 to 4 mph was less than 5%.

### Effect of Tree on Air Velocities

Figure 2 shows that tree resistance significantly reduced measured air velocities with respect to velocities in free flow predicted by a computer sprayer model for a stationary sprayer (1). Sites 1, 2, 3, and 4 were essentially unobstructed, while air flow to sites 5, 6, 7, 8, and 9 was obstructed by the tree canopy. Except for site 3, velocities measured at unobstructed sites were within 12 mph of predicted velocities. At all sites within the canopy, measured air velocities were more than 27 mph less than predicted velocities.

### Effect of Air Volume Flow Rate and Outlet Velocity

Figure 3 is a plot of air velocities at each site for sprayer No. 1 operated at PTO speeds of 250, 350, 450, and 550 rpm. In all trials, the 250 rpm speed produced velocities which were 30-40% less than velocities produced by the 550 rpm speed. At sites 8 and 9, 250 and 350 rpm speeds did not produce velocities which could be detected above ambient wind velocities.

## CONCLUSIONS

- Tree foliage reduced air velocities in sprayer jets by deflecting, spreading, and absorbing the jet energy. At sites where we would expect 50 mph air velocities without obstructions, we measured only 12 mph

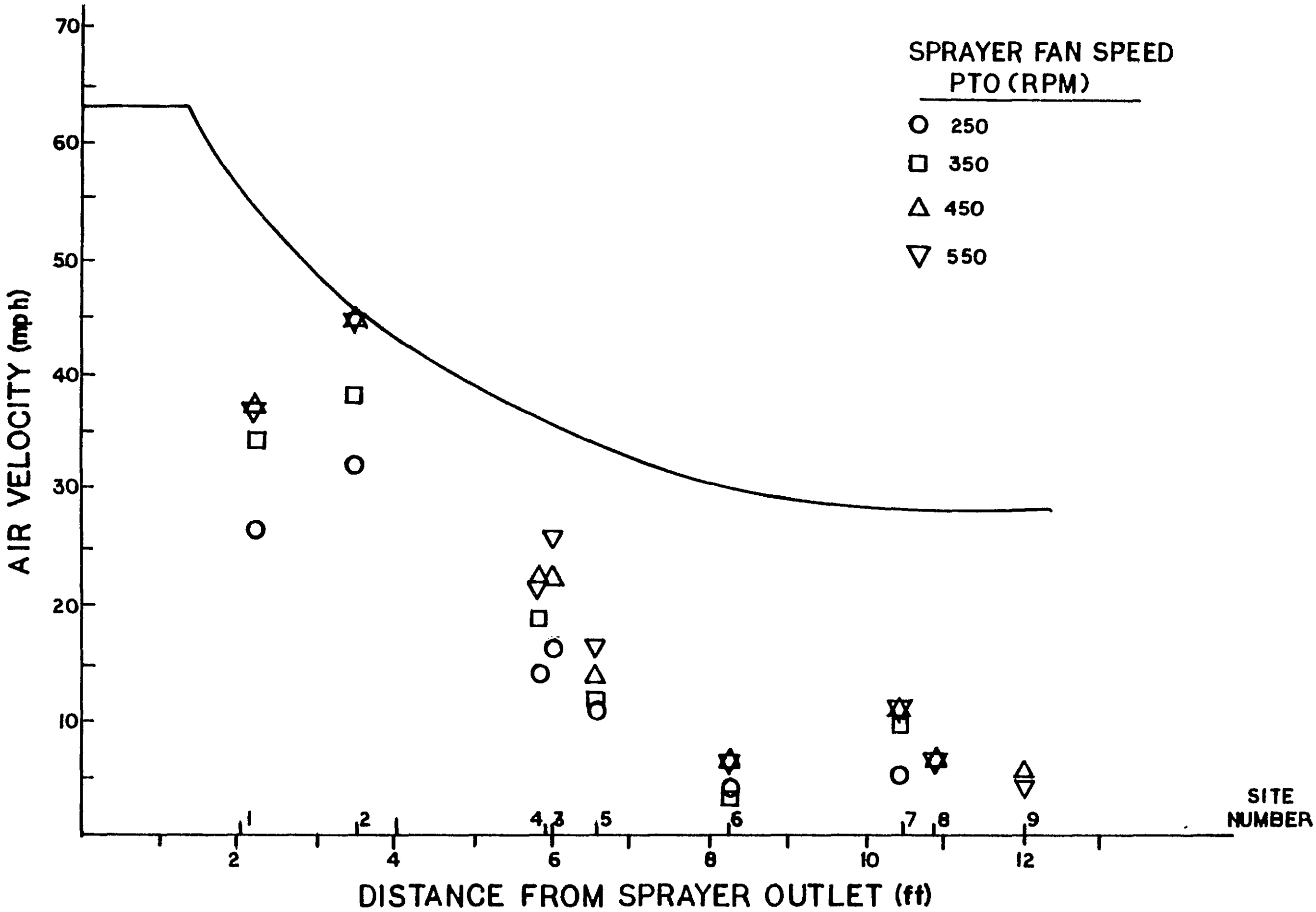


FIG. 3.—Air velocities in tree from sprayer No. 1 at four PTO speeds. Solid line is air velocity predicted by computer model for a free jet, based on outlet velocity for 550 rpm PTO speed on radial line through site no. 2.

within the tree. To achieve more uniform coverage of spray materials over an entire tree, we must produce the optimum droplet-deposition velocity throughout the canopy. This may be accomplished by better sprayer design, by changing tree shape, or by other means, such as increasing the range of velocities which will effectively deposit droplets on plant surfaces.

- Sprayers traveling at 4 mph produced jets with air velocities 10-15% less than when traveling at 2 mph. Further increases in travel speed would further reduce sprayer-jet velocities. In addition, air jets are deflected more at higher travel speeds (5). Spraying while traveling at higher speeds usually results in less uniform distribution of spray material over a tree than spraying at lower speeds.

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# Relationship of Orchard Location and Nutrition to Scarf Skin of Rome Beauty Apples

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## INTRODUCTION

Scarf skin is described as a gray flecking or milky appearance which is a characteristic of certain cultivars such as Stayman and Rome Beauty. In some years it is also found on Jonathan, Delicious, and other cultivars. The visual symptoms of scarf skin are likely due to cell separations several cell layers below the surface of the fruit, which result in air spaces (5). Dayton (3) working with Stayman proposed that these spaces affected light passage through the colored hypodermal cells. Light would likely be reflected by the air spaces, causing the whitish appearance. Scarf skin is more severe on the green side of the fruit and severity increases with fruit size (4). A survey of several Ohio orchards revealed large differences in scarf skin severity in 1982 (5).

In 1977, Byers (1) drew attention to a commercial problem with scarf skin in Indiana. The U. S. Federal/State Inspection Service lowered the grade when more than 15% of the skin surface was affected by scarf skin. Byers could not identify differences in scarf skin level due to spray program or strain of Rome Beauty. However, results indicated that differences in severity were relative to fruit position on the tree and increased on vigorous trees.

Several investigators (4, 6, 7) have shown that some fungicides, particularly benomyl, can increase severity of scarf skin. The critical period for scarf skin development occurs during the 40-day period immediately following petal fall (4). Analyses of apple skin with increasing severities of scarf skin indicate that increased concentrations of Al, Ca, and Mn are associated with severe scarf skin.

The present study was conducted to determine if the degree of scarf skin was associated with leaf nutrient level in numerous Ohio orchards.

## MATERIALS AND METHODS

In 1983, a sample of 40 mid-terminal leaves was collected in mid-August from 18 Rome Beauty orchards in three geographic regions of Ohio. At harvest in October, a random sample of 50 fruit was secured from each orchard. Care was taken in sampling to insure that leaves or fruit from 20-25 trees/site were included. Individual fruit weight and a visual rating of scarf skin on the green side of the fruit were recorded, using a rating system (4) with values of 1 = no scarf skin visible to 5 = severe scarfing as indicated by a gray milky appearance.

The green side of the apples was then peeled to remove as little flesh with the skin as possible. The peel tissue and the leaves mentioned previously were dried in a forced draft oven at 70° C and ground. Analysis of the tissue for P, K, Ca, Mg, Mn, Fe, B, Cu, Zn, Al, and Na was accomplished by plasma emission spectrophotometry by the OARDC Research and Extension Analytical Laboratory. Nitrogen in the tissue was analyzed by macro-Kjeldahl.

To determine if applications of nutrients to the fruit influenced the expression of scarf skin, four commonly applied nutrients at two or three rates for each compound (Table 4) were applied to fruit on Lawspur Rome Beauty/M7 trees planted in 1979. Three clusters on each of 10 replicate trees were dipped in the solutions at petal fall (PF), PF + 10 days, and PF + 20 days. At harvest, fruit weight and level of scarf skin were determined as previously described.

## RESULTS AND DISCUSSION

Average fruit size (Table 1) varied 45% from the smallest (133 g) to the largest (239 g), and the scarf skin rating varied 55% from the most severe (4.8) to least severe (2.2). No consistent difference existed in the selected geographical regions of Ohio, with the highest average level of scarf skin found in the northeastern region (3.87), followed by the central (3.70) and northern (3.37) regions. However, there appeared to be a more consistent relationship between fruit size and level of scarf skin in the northeastern region.

From the orchards tested, various comparisons were made to see if a pattern of increasing severity was associated with rootstock, cultivar strain, tree age, or soil type. Although it must be recognized that this effort cannot be concise due to the extreme variability in all of these factors, none of these factors appeared to indicate a pattern which could explain the differing levels of scarf skin. Lynd Orchards reported an increase in the severity of scarf skin in 1983, which could relate to the inclusion of benomyl in early sprays for mildew control. In other orchards sampled in both 1982 and 1983, the scarf skin levels at Peace Valley declined in 1983, while levels at Lane's Orchard and Overlook were more severe. Scarf levels at Ohio Orchard and Bachman Orchards were similar in the 2 years.

Of interest is the difference in scarf skin levels between Bachman Orchards (2.5 and 2.6 ratings) and Overlook Orchards (4.6 and 4.6 ratings). These Central Ohio orchards adjoin each other. The most obvious difference between spray programs in these orchards was three applications of benomyl during the critical period for scarf development at Overlook and no benomyl applied in Bachman Orchard. The role of benomyl in increasing scarf skin has been shown previously (4, 6, 7) and the data add evidence to the need to avoid benomyl applications at PF and the next 5 weeks on Rome Beauty. Severe scarf skin (rating of 4.8) was also found on Delicious at Overlook Farm in 1983.

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A comparison of the leaf nutrient levels showed the expected variation, but no particular deficiency or toxicity levels were identified (Table 2). Most orchards had generally adequate levels with the exception of several orchards having levels of potassium below the desired threshold of 1.0%.

When leaf nutrient levels were correlated with average fruit weight, a slight negative relationship existed with leaf Mg. Of all the elements analyzed, the only significant relationship which existed was between scarf skin and Al level in the leaf. When the leaf nutrient level was correlated with the corresponding nutrient in the apple peel (Table 3), several strong positive relationships were evident with P, K, Ca, Mn, B, Zn, and Al. A negative relationship for Mg existed between leaf and fruit peel (Table 2). Several elements (N, Fe, Cu, Na) demonstrated no relationship between leaf and peel levels.

Peel N had a slight positive relationship with fruit size and with increasing severity of scarf skin. This finding supports previous observations that scarf skin is more severe on the green side of the fruit (4, 5) and the general relationship suggested by Byers (1) that scarf skin was more severe on vigorous trees.

As in previous work (5), increasing severity of scarf skin was related to increasing peel levels of Mn and Al. In the present study, the correlation with skin Ca was not significant as previous studies have shown, partly due to the variability between orchards in Ca levels.

There was little evidence that the three nutrient dips during the critical period for development of the disorder influenced either scarf skin level or fruit weight (Table 4). As shown previously, enclosing the cluster in an aerated polyethylene bag decreased fruit size and dramatically decreased scarf skin (Table 4).

From this work and that reported previously (5), there appears to be an association between high peel levels of Mn and Al and scarf skin level. However, this

**TABLE 1.—Scarf Skin Level on Law or Lawspur Rome Apples from Various Ohio Orchards, 1983.**

| Location | Strain/Stock | Fruit wt (g) | Scarf Rating† | Correlation Scarf and Size‡ |
|---|---|---|---|---|
| **Northeastern Ohio** | | | | |
| Whitehouse | Law/9/106 | 191 | 4.2bcd | −0.27 |
| Huffman | Law/111 | 185 | 4.8a | 0.35* |
| Peace Valley | Lawspur/9/106 | 239 | 4.4abc | 0.23 |
| | Law/106 | 183 | 3.7efgh | 0.52** |
| | Law/106 | 180 | 3.7efgh | 0.42** |
| | Lawspur/Seedling | 215 | 4.1bcd | 0.56** |
| | Law/106 | 201 | 3.7efgh | 0.34* |
| | Rome Seedling | 186 | 3.3hi | 0.39** |
| Papania | Law/106 | 212 | 3.9defg | −0.07 |
| Hartley | Law/111 | 200 | 4.3bc | 0.39** |
| Bare | Law/Seedling | 144 | 3.1il | 0.37* |
| | Law/7 | 181 | 3.1il | 0.03 |
| Stahl | Law/26 | 135 | 4.0cdef | 0.26 |
| **Northern Ohio** | | | | |
| Burnham | Law/Seedling | 141 | 3.5ghi | 0.29* |
| | Lawspur/111 | 187 | 2.8lm | 0.06 |
| Dodd | Lawspur/111 | 134 | 2.7lm | 0.29* |
| Moore | Law/C6 | 166 | 4.3bc | −0.04 |
| Steinbauer (sand) | Law/7 | 230 | 3.4ghi | 0.20 |
| (loamy) | Law/7 | 190 | 3.6fgh | 0.22 |
| Taylor | Lawspur/9/11 | 140 | 3.3hi | 0.22 |
| **Central Ohio** | | | | |
| Hartzler | Law/Seedling | 155 | 2.2n | 0.28* |
| Lane | Lawspur/9/106 | 186 | 4.4abc | 0.10 |
| Ohio Orchard | Law/C6 | 145 | 3.6fgh | 0.03 |
| | Law/7A | 173 | 3.4ghi | 0.07 |
| Overlook | Lawspur/9/106 | 170 | 4.6ab | −0.03 |
| | Law/9/106 | 179 | 4.6ab | 0.29* |
| Bachman | Lawspur/111 | 160 | 2.6mn | 0.09 |
| | Law/Seedling | 162 | 2.5mn | 0.16 |
| Lynd (pond) | Lawspur/M7 | 169 | 4.0cdef | 0.11 |
| (oil) | Lawspur/M7 | 152 | 4.4abc | 0.18 |
| (Dave) | Law/Seedling | 133 | 4.4abc | 0.02 |

†Scarf skin rated as follows: 1 = no scarf to 5 = severe scarf. Means with a letter in common are not different, Duncan's multiple range test, 5% level.

‡Correlation: * significant 5%, ** significant 1%.

**TABLE 2.—Nutrient Levels in Leaves of Law or Lawspur Rome Beauty Apple Trees in 1983 from Various Ohio Orchards.**

| | | Percent Dry Weight | | | | | ppm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Location** | **Strain/Stock** | **N** | **P** | **K** | **Ca** | **Mg** | **Mn** | **Fe** | **B** | **Cu** | **Zn** | **Al** | **Na** |
| **Northeastern Ohio** | | | | | | | | | | | | | |
| Whitehouse | Law/9/106 | 2.44 | 0.16 | 1.34 | 1.28 | 0.21 | 187 | 79 | 23 | 7 | 50 | 312 | 81 |
| Huffman | Law 111 | 2.52 | 0.24 | 1.24 | 1.14 | 0.19 | 154 | 52 | 23 | 5 | 46 | 88 | 11 |
| Peace Valley | Lawspur/9/106 | 2.24 | 0.25 | 1.33 | 1.30 | 0.22 | 40 | 55 | 26 | 5 | 102 | 74 | 40 |
| | Law/106 | 2.30 | 0.16 | 1.19 | 1.09 | 0.20 | 36 | 50 | 25 | 4 | 190 | 96 | 28 |
| | Law/106 | 2.50 | 0.26 | 1.31 | 1.37 | 0.20 | 26 | 50 | 25 | 4 | 134 | 82 | 26 |
| | Lawspur/Seedling | 2.40 | 0.26 | 1.32 | 1.15 | 0.21 | 55 | 56 | 25 | 4 | 120 | 82 | 12 |
| | Law/106 | 2.36 | 0.17 | 1.06 | 1.28 | 0.20 | 59 | 55 | 22 | 5 | 90 | 82 | 30 |
| | Rome Seedling | 2.56 | 0.17 | 0.95 | 1.04 | 0.26 | 39 | 53 | 22 | 4 | 87 | 68 | 37 |
| Papania | Law/106 | 2.56 | 0.24 | 1.42 | 1.08 | 0.21 | 187 | 71 | 24 | 5 | 275 | 216 | 45 |
| Hartley | Law/111 | 2.36 | 0.17 | 0.94 | 1.08 | 0.30 | 161 | 67 | 20 | 5 | 43 | 222 | 51 |
| Bare | Law/Seedling | 2.36 | 0.21 | 0.87 | 1.25 | 0.29 | 43 | 50 | 21 | 4 | 117 | 158 | 15 |
| | Law/7 | 2.30 | 0.20 | 1.12 | 1.15 | 0.23 | 28 | 53 | 21 | 5 | 90 | 114 | 13 |
| Stahl | Law/26 | 2.62 | 0.23 | 0.94 | 1.02 | 0.33 | 43 | 72 | 19 | 5 | 115 | 311 | 19 |
| **Northern Ohio** | | | | | | | | | | | | | |
| Burnham | Law/Seedling | 2.40 | 0.22 | 1.33 | 1.18 | 0.23 | 28 | 64 | 35 | 6 | 174 | 143 | 57 |
| | Lawspur/111 | 2.08 | 0.30 | 1.41 | 0.84 | 0.19 | 37 | 55 | 29 | 5 | 80 | 92 | 33 |
| Dodd | Lawspur/111 | 2.60 | 0.12 | 1.04 | 0.79 | 0.25 | 56 | 84 | 23 | 7 | 13 | 52 | 11 |
| Moore | Law/C6 | 2.30 | 0.14 | 0.77 | 1.08 | 0.33 | 173 | 41 | 21 | 3 | 52 | 91 | 22 |
| Steinbauer (sand) | Law/7 | 2.44 | 0.25 | 1.41 | 0.88 | 0.24 | 93 | 72 | 33 | 6 | 267 | 71 | 21 |
| (loamy) | Law/7 | 2.06 | 0.25 | 1.03 | 1.18 | 0.30 | 249 | 50 | 28 | 5 | 129 | 52 | 23 |
| Taylor | Lawspur/9/111 | 2.22 | 0.13 | 1.13 | 0.81 | 0.21 | 42 | 69 | 20 | 5 | 118 | 102 | 10 |
| **Central Ohio** | | | | | | | | | | | | | |
| Hartzler | Lawspur/Seedling | 2.30 | 0.15 | 0.87 | 1.15 | 0.28 | 57 | 50 | 21 | 4 | 13 | 75 | 22 |
| Lane | Lawspur/9/106 | 1.96 | 0.23 | 1.25 | 1.25 | 0.23 | 229 | 52 | 25 | 4 | 83 | 146 | 15 |
| Ohio Orchard | Law/C6 | 1.98 | 0.16 | 0.90 | 1.17 | 0.31 | 173 | 41 | 16 | 3 | 58 | 80 | 15 |
| | Law/7A | 2.16 | 0.13 | 1.02 | 1.03 | 0.25 | 171 | 44 | 19 | 4 | 48 | 55 | 7 |
| Overlook | Lawspur/9/106 | 2.32 | 0.17 | 1.39 | 1.21 | 0.21 | 129 | 52 | 26 | 5 | 35 | 76 | 26 |
| | Law/9/106 | 2.46 | 0.15 | 1.32 | 1.20 | 0.20 | 133 | 44 | 26 | 4 | 34 | 79 | 26 |
| Bachman | Lawspur/111 | 2.46 | 0.16 | 1.40 | 0.85 | 0.17 | 128 | 62 | 33 | 6 | 16 | 66 | 19 |
| | Law/Seedling | 2.00 | 0.18 | 1.07 | 1.59 | 0.29 | 32 | 43 | 26 | 4 | 14 | 88 | 36 |
| Lynd (pond) | Lawspur/7 | 2.84 | 0.14 | 0.98 | 0.99 | 0.26 | 34 | 57 | 21 | 5 | 16 | 186 | 29 |
| (oil) | Lawspur/7 | 2.30 | 0.16 | 0.96 | 1.14 | 0.27 | 27 | 57 | 22 | 4 | 16 | 221 | 38 |
| (Dave) | Law/Seedling | 2.30 | 0.29 | 1.46 | 1.24 | 0.24 | 23 | 52 | 22 | 4 | 14 | 189 | 30 |
| wt | | –0.05 | 0.05 | 0.27 | –0.02 | –0.46* | 0.88** | 0.02 | 0.03 | 0.01 | 0.25 | –0.16 | 0.09 |
| Scarf | | 0.13 | 0.16 | 0.23 | 0.21 | –0.07 | –0.03 | –0.13 | –0.10 | –0.15 | 0.00 | 0.34* | 0.17 |
| Skin Level with Leaf Level | | 0.01 | 0.62** | 0.68** | 0.34* | –0.42* | 0.29 | –0.02 | 0.77** | 0.21 | 0.55* | 0.67** | 0.16 |

**TABLE 3.—Nutrient Levels in Skin of Law or Lawspur Rome Beauty Apples in 1983 from Various Ohio Orchards.**

| Location | Strain/Stock | Percent Dry Weight | | | | | ppm | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | P | K | Ca | Mg | Mn | Fe | B | Cu | Zn | Al | Na |
| **Northeastern Ohio** | | | | | | | | | | | | | |
| Whitehouse | Law/9/106 | 0.68 | 0.07 | 0.76 | 0.05 | 0.08 | 14 | 23 | 21 | 3 | 3 | 25 | 13 |
| Huffman | Law/111 | 1.04 | 0.12 | 0.66 | 0.10 | 0.10 | 19 | 24 | 26 | 3 | 6 | 44 | 16 |
| Peace Valley | Lawspur/9/106 | 0.84 | 0.11 | 0.65 | 0.11 | 0.11 | 7 | 19 | 27 | 3 | 7 | 17 | 5 |
| | Law/106 | 0.68 | 0.10 | 0.65 | 0.08 | 0.10 | 7 | 21 | 22 | 3 | 9 | 14 | 4 |
| | Law/106 | 0.62 | 0.08 | 0.68 | 0.07 | 0.09 | 7 | 18 | 30 | 3 | 6 | 14 | 5 |
| | Lawspur/Seedling | 0.60 | 0.08 | 0.59 | 0.07 | 0.08 | 6 | 21 | 19 | 2 | 5 | 13 | 5 |
| | Law/106 | 0.56 | 0.10 | 0.63 | 0.12 | 0.10 | 7 | 20 | 28 | 2 | 4 | 15 | 2 |
| | Rome/Seedling | 0.60 | 0.09 | 0.57 | 0.08 | 0.08 | 6 | 19 | 24 | 1 | 6 | 11 | 8 |
| Papania | Law/106 | 0.72 | 0.08 | 0.59 | 0.07 | 0.08 | 14 | 22 | 16 | 2 | 9 | 27 | 2 |
| Hartley | Law/111 | 0.66 | 0.07 | 0.52 | 0.06 | 0.08 | 13 | 19 | 18 | 2 | 3 | 25 | 2 |
| Bare | Law/Seedling | 0.56 | 0.09 | 0.53 | 0.11 | 0.08 | 6 | 21 | 25 | 2 | 11 | 40 | 6 |
| | Law/7 | 0.58 | 0.09 | 0.59 | 0.10 | 0.10 | 5 | 19 | 18 | 3 | 7 | 19 | 5 |
| Stahl | Law/26 | 0.52 | 0.08 | 0.57 | 0.06 | 0.07 | 5 | 22 | 17 | 2 | 11 | 38 | 3 |
| **Northern Ohio** | | | | | | | | | | | | | |
| Burnham | Law/Seedling | 0.76 | 0.12 | 0.75 | 0.11 | 0.10 | 6 | 25 | 42 | 3 | 25 | 27 | 29 |
| | Lawspur/111 | 0.72 | 0.14 | 0.85 | 0.07 | 0.10 | 5 | 19 | 32 | 4 | 21 | 22 | 25 |
| Dodd | Lawspur/111 | 0.48 | 0.07 | 0.54 | 0.08 | 0.08 | 5 | 19 | 24 | 3 | 4 | 9 | 9 |
| Moore | Law/C6 | 0.56 | 0.08 | 0.63 | 0.09 | 0.10 | 16 | 27 | 26 | 2 | 3 | 23 | 7 |
| Steinbauer (sand) | Law/7 | 0.66 | 0.12 | 0.75 | 0.07 | 0.09 | 8 | 24 | 36 | 3 | 14 | 16 | 4 |
| (loamy) | Law/7 | 0.46 | 0.11 | 0.60 | 0.11 | 0.10 | 20 | 18 | 36 | 3 | 21 | 14 | 12 |
| Taylor | Lawspur/9/111 | 0.64 | 0.08 | 0.75 | 0.05 | 0.08 | 4 | 22 | 20 | 2 | 5 | 15 | 9 |
| **Central Ohio** | | | | | | | | | | | | | |
| Hartzler | Law/Seedling | 0.52 | 0.08 | 0.55 | 0.10 | 0.08 | 6 | 18 | 22 | 2 | 3 | 14 | 5 |
| Lane | Lawspur/9/106 | 0.76 | 0.11 | 0.89 | 0.05 | 0.09 | 42 | 24 | 24 | 3 | 6 | 24 | 9 |
| Ohio Orchard | Law/C6 | 0.68 | 0.07 | 0.58 | 0.07 | 0.08 | 22 | 20 | 13 | 3 | 5 | 19 | 25 |
| | Law/7A | 0.56 | 0.06 | 0.62 | 0.05 | 0.07 | 14 | 16 | 19 | 2 | 4 | 9 | 14 |
| Overlook | Lawspur/9/106 | 0.74 | 0.09 | 0.76 | 0.08 | 0.10 | 15 | 23 | 21 | 2 | 4 | 14 | 4 |
| | Law/9/106 | 0.60 | 0.10 | 0.80 | 0.07 | 0.10 | 14 | 25 | 22 | 3 | 5 | 18 | 8 |
| Bachman | Lawspur/111 | 0.62 | 0.08 | 0.79 | 0.06 | 0.10 | 15 | 20 | 29 | 2 | 3 | 11 | 2 |
| | Law/Seedling | 0.62 | 0.10 | 0.64 | 0.08 | 0.07 | 4 | 27 | 29 | 2 | 3 | 15 | 29 |
| Lynd (pond) | Lawspur/7 | 0.70 | 0.07 | 0.66 | 0.08 | 0.08 | 5 | 22 | 24 | 2 | 4 | 36 | 10 |
| (oil) | Lawspur/7 | 0.62 | 0.07 | 0.59 | 0.09 | 0.08 | 4 | 21 | 28 | 2 | 3 | 39 | 5 |
| (Dave) | Lawspur/Seedling | 0.62 | 0.10 | 0.72 | 0.10 | 0.09 | 5 | 19 | 25 | 2 | 4 | 44 | 15 |
| wt | | 0.39* | 0.09 | 0.21 | −0.26 | 0.15 | −0.00 | 0.01 | −0.12 | −0.05 | −0.19 | −0.31 | −0.28 |
| Scarf | | 0.49* | 0.08 | 0.20 | −0.03 | 0.27 | 0.35* | 0.29 | −0.19 | −0.06 | −0.18 | 0.45* | −0.19 |

*Significant at 5% level or lower.

TABLE 4.—Influence of Nutritional Dips on Development of Scarf Skin on Lawspur Rome Apples at OARDC, Wooster, 1983.

| Treatment | Rate/ Liter | Number Fruit/Three Spurs | Av. Fruit wt (g) | Scarf Rating* |
|---|---|---|---|---|
| CK | | 2.5 | 145 | 2.7 |
| Solubor | 2.4g | 2.3 | 147 | 3.0 |
| Solubor | 4.8g | 2.3 | 144 | 3.2 |
| $KNO_3$ | 7.2g | 2.5 | 157 | 3.3 |
| $KNO_3$ | 14.4g | 2.8 | 149 | 3.3 |
| $KNO_3$ | 21.6g | 1.5 | 159 | 2.3 |
| Mg Sequestrene | 2.4g | 1.9 | 158 | 3.1 |
| Mg Sequestrene | 4.8g | 1.4 | 159 | 2.9 |
| Sorba ZBK | 2.5ml | 2.0 | 146 | 3.3 |
| Sorba ZBK | 5.0ml | 1.9 | 145 | 2.7 |
| Plastic Bag CK | | 1.4 | 119 | 1.2 |
| LSD .05 = | | NS | 18 | .61 |

*Scarf skin rated as fillows: 1 = no scarf to 5 = severe scarf.

relationship does not appear to be strong enough to be considered as the primary cause of scarf skin. A weak association may also exist for N, but again decreasing N is not likely to eliminate scarf skin. Again, it appears that benomyl applications during the critical period for scarf skin development can dramatically increase the severity of the disorder. However, relatively severe scarf skin occurred in several orchards which did not include benomyl in their spray programs.

It appears that prudent practices to contain scarf skin are to prune and fertilize in moderation so that fruit size is moderate and to avoid benomyl sprays for the 40 days following PF. These procedures will not eliminate scarf skin, but should help to keep it at a moderate level in most years.

With the information available we are unable to explain the large differences between orchards or years in the expression of scarf skin. Since Rome Beauty is the second most important cultivar in Ohio and the 1982 survey (2) indicates that 43% of the Rome trees are 5 years of age or less, it is appropriate to continue research to identify a practical means of lessening the severity of scarf skin.

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# The Effects of Bee Lure on Honey Bee (*Apis mellifera*) Pollination of Apples

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## INTRODUCTION

Chemical attractants applied as sprays to lure honey bees to specific crops have been popular during recent years. Burgett and Fisher (1) evaluated the effects of a wettable powder chemical attractant, Beeline,[3] on foraging populations in red clover (*Trifolium pratense*) fields. Sheppard, Jaycox, and Parise (3) tested Beeline on soybeans (*Glycine max*) in Illinois. Increased seed set was not observed on either soybeans or red clover.

Another attractant, Bee Lure, is a colored syrup made by Helene Chemical Co. The syrup is a high conversion corn syrup comprised of sugars, strawberry flavoring, red dye, and a preservative. Rajotte and Fell (2) tested Bee Lure in Virginia to determine if it increased honey bee pollination and subsequent fruit set on apples. They were unable to find any difference between the number of foraging bees on treated trees when compared to controls.

## MATERIALS AND METHODS

Because of continued interest in Bee Lure in Ohio, we tested the attractant during 1979 and 1980. Bee Lure (1 gallon to 50 gallons of water) was applied to mature Jonathan (1979) and Red Delicious (1980) dwarf apple trees. A high-pressure hand gun was used to apply the spray to drip at pink, with a repeat application at full bloom. The treatments were arranged as a randomized complete block with eight single tree replications, as was the control group. Control trees were sprayed to drip with water.

Fruit set was determined by counting flower clusters on two limbs per tree, followed by counting fruit remaining after natural drop was complete. During 1979 trees were treated on May 4 (pink) and May 8 (full bloom). Honey bee activity was recorded during the day from 0900-1700 hours on May 8-13, 1979. Temperature range was 65° to 90° F (18.3° to 32.2° C).

During 1980 trees were sprayed on May 13 and May 16. Daily bee activity counts were taken from 0900-1630 hours on May 13 and May 16. Rain prohibited further counts. The temperature range was 50° to 72° F (10° to 22.2° C).

During the days immediately following attractant application, bee activity counts were made. After walking around a particular tree for a 1-minute interval, an observer recorded the number of foraging bees. Observations were also conducted to determine the average length of time which foragers stayed on blossoms (Table 1). Foraging bees on eight treated trees and eight control trees were counted 31 times from 0800 until 1700 hours during 1979. The temperature averaged 76.8° F (24.9° C) during the test period.

Poor foraging conditions limited the number of observations during 1980. Twenty-four observations were made on 16 Red Delicious trees (8 treated, 8 control) from 0900-1630 hours. The temperature average was 65.4° F (18.6° C) during the test period.

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**TABLE 1.—Effects of Bee Lure on Honey Bee Activity on Jonathan (1979) and Delicious (1980) Apple Trees.**

| Treatment | Mean Number of Foraging Bees/Tree (±) SE | Mean Time Spent on Blossoms | Mean Temperature |
|---|---|---|---|
| Bee Lure 1979 | 8.56 ± .91* | 3.6 sec/bee | 76.8° F (24.9° C) |
| Control 1979 | 7.31 ± .89* | 3.9 sec/bee | |
| Bee Lure 1980 | 10.19 ± 1.21* | 3.3 sec/bee | 64.4° F (18.6° C) |
| Control 1980 | 9.67 ± 1.89* | 3.4 sec/bee | |

*Mean differences not significant at 5%.

**TABLE 2.—Effects of Bee Lure on Fruit Set of Jonathan (1979) and Delicious (1980) Apple Trees.**

| Treatment | Year | Flower Clusters Counted | No. of Fruit | Percent Set |
|---|---|---|---|---|
| Bee Lure | 1979 | 1615 | 267 | 16.5* |
| Control | 1979 | 1704 | 255 | 15.1* |
| Bee Lure | 1980 | 708 | 41 | 5.8* |
| Control | 1980 | 742 | 57 | 7.7* |

*Mean differences not significant at t = .05%.

## RESULTS

During both years, the mean numbers of foraging bees were greater on treated than on control trees. However, those mean differences were not significant (t .05) (Table 1).

As stated earlier, control trees were sprayed to drip with water. This procedure decreases the attractiveness of control trees to foragers by diluting blossom nectar and washing pollen away. Foragers were on blossoms from 3.3 to 3.9 seconds. Even though no counts were taken, honey bees were routinely observed collecting syrup from leaf surfaces immediately after attractant was applied. Also, there were increased populations of other insects (Diptera, Lepidoptera, Hymenoptera).

No significant difference could be shown in percent fruit set (number of fruit set/number of clusters counted) (t .05) (Table 2) within respective years.

The attractant applied to drip 2 consecutive years did not increase fruit set significantly (t .05), although treated trees exhibited more bee activity. It must be concluded that the attractant did not entice foragers to apple blossoms any greater than water applied to control trees.

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# Influence of Various Times of Summer Hedging on Yield and Growth of Apple Trees

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## INTRODUCTION

Summer pruning has been advocated as a means of controlling vegetative growth of apples (1, 9) and as an assist in containing intensely planted trees (3, 4, 8) within their allotted space. Most studies which compare the influence of various times of summer pruning (3, 8, 9) on growth and fruiting utilized selective hand pruning.

Results from these studies indicated that the earlier summer pruning was performed, the greater the amount of regrowth. Delaying until mid-August greatly reduced regrowth (3, 8, 9). July and August pruning maintained the number of fruit/tree and July pruning increased the number of fruit borne in the canopy interior, compared to the unpruned control (8). July and August, but not September, pruning reduced corkspot. The authors concluded that August pruning was on balance the most desirable. They expressed the concern that the relatively large percentage of canopy removed in these studies resulted in undesirable effects such as decreased fruit size and soluble solids.

Hayden and Emerson (4) used a mechanical hedger and suggested that cutting the new growth twice (July and August) was preferred for tree size containment. However, results from pruning at other times were not reported. This technique also promoted better spray penetration, improved light conditions, and resulted in better fruit color and more uniform ripening. The authors stressed that dormant hedging resulted in excessive shoot proliferation in the outer canopy and required considerable detailed corrective pruning, while trees summer hedged twice each year did not have this problem.

Ferree (2) also reported a proliferation of shoot growth on the canopy periphery, but did find that dormant hedging achieved a reduction in canopy spread. When combined with biennial hand pruning, dormant hedging was an acceptable practice. Several reports indicate that the combination of annual hedging followed by hand pruning removes an excess of leaf surface and markedly reduces yields (2, 4).

The present study was initiated to determine the influence of various timings of mechanical summer hedging on tree size containment and productivity.

## MATERIALS AND METHODS

Trees of Golden Delicious and Melrose on M26 were planted at a spacing of 12 x 20 ft in 1968 in east-west rows and trained as central leaders. The trees had filled their allotted space by 5 years of age and containment pruning was practiced to maintain a tree height and spread of 10 ft. In the early spring of 1977, all trees were lightly dormant pruned. The following summer, hedging treatments were applied, cutting two sides of the tree: 1) check: annual dormant hand pruned; 2) summer hedged in June and July; 3) summer hedged in June and August; 4) summer hedged in July and August; 5) summer hedged in June, July, and August; 6) dormant hedged. The cutter bar was set at an angle so that the top of the tree had a spread of 5 ft and the bottom 10 ft. The trees were topped at 10 ft by hand in 1977 through 1979 and mechanically in August in subsequent years. The treatments were arranged as a split plot with cultivars as the main plot and pruning treatments as the split plots with eight single-tree replications.

Trunk circumferences and dry weights of all prunings were recorded annually (dry weight in 1977 and 1978 and fresh weight in other years). The entire yield from each tree was graded each year on an FMC weight sizer and the number of fruit in each of the following size classes recorded: Size 1 (3-1/8 inch diameter and larger); Size 2 (2-7/8 to 3-1/16 inch diameter); Size 3 (2-1/4 to 2-3/4 inch diameter); Size 4 (smaller than 2-1/4 inch diameter).

In 1979 a sample of 40 fruit per tree were rated for russet (1 = none to 5 = severe), color (1 = yellow to 5 = green) and a 10-fruit subsample was used to determine fruit soluble solids and firmness. In September, a pole marked at 50 cm intervals was placed in a north-south transect 100 cm above the soil surface. A Li-Cor 185 radiometer with a 190-S quantum sensor was used to take spot light readings on a bright, sunny day and percent full sun was calculated. In 1981, canopy openness was assessed using fisheye photography with percent sky values based on standards supplied by Lakso (5, 6).

## RESULTS AND DISCUSSION

In 1977 a frost during bloom eliminated the crop on Melrose (Table 1). Golden Delicious produced a reasonable crop mostly on lateral bloom on 1-year-old wood. Over the 5 years of this study, the various pruning treatments had little influence on total yield per tree. After 1979, Golden Delicious produced more than Melrose and averaged 22% more over the period of the study. The performance in the previous 5 years was similar, with Golden Delicious producing 26% more than Melrose. The interaction between cultivar and pruning treatment was not significant in any year.

Fruit size distribution of Melrose was consistently large and generally was not influenced by pruning treatment. After 3 years of these treatments, fruit size of the dormant hedged Golden Delicious trees was larger than from the summer hedged trees (Table 2). Generally, fruit from the check trees tended to be larger than the summer hedged trees, but the differences were not

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**TABLE 1.—Influence of Timing of Summer Hedging on Yield/Tree (lb) of Two Cultivars on M26 Rootstock.**

| Treatments | 1977 | | 1978 | | 1979 | | 1980 | | 1981 | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Golden Delicious | Melrose | Golden Delicious | Melrose | Golden Delicious | Melrose | Golden Delicious | Melrose | Golden Delicious | Melrose | Golden Delicious | Melrose |
| Check (Hand, Dormant | 193 | | 136 | 121 | 369 | 111 | 300 | 262 | 196 | 84 | 199 | 173 |
| June, July | 118 | | 113 | 145 | 351 | 74 | 260 | 235 | 178 | 45 | 184 | 159 |
| June, August | 126 | | 124 | 132 | 312 | 81 | 258 | 217 | 200 | 100 | 204 | 158 |
| July, August | 118 | | 113 | 125 | 360 | 98 | 270 | 272 | 189 | 70 | 210 | 176 |
| June, July, August | 123 | | 131 | 79 | 322 | 72 | 234 | 210 | 156 | 52 | 193 | 138 |
| Hedged, Dormant | 136 | | 119 | 72 | 391 | 89 | 280 | 225 | 208 | 50 | 226 | 153 |
| Average | 135 | | 122 | 112 | 350a | 87b | 267a | 237b | 188a | 67b | 202a | 169b |

always significant. Time of summer hedging had little influence on fruit size distribution. The adverse effect of manual summer pruning on fruit size has been shown in several other studies (7, 8, 10).

Generally, Melrose trees made more vegetative growth than Golden Delicious trees and subsequently more growth was removed (Table 3). When the summer hedging treatments are compared, it is interesting that a very large proportion of the vegetative growth was removed in June. This is particularly striking when it is realized that two of the July and August treatments had been pruned previously in June and thus would only contribute regrowth. Dormant hedging did not remove as much tissue as the summer hedging due mostly to the presence of the leaves on the summer clippings.

Dormant pruning by hand removed a greater amount of tissue than any of the hedging treatments (Table 3, Fig. 1). This was true with all treatments after 1979 when it became obvious that some thinning out pruning was necessary, particularly with Melrose to maintain fruit quality. Generally, treatments 1 (hand-pruned control) and 6 (dormant hedged) required more dormant pruning than the summer hedged trees.

In July, more tissue was removed from trees in treatment 4 (pruned July and August) because treatments 2 (pruned June and July) and 5 (pruned June, July, and August) had previously been pruned in June and thus only regrowth was cut on these treatments (Fig. 1). Previous pruning in June or July or both had little consistent influence on August pruning weights.

In 1979 it was obvious that hand thinning-out pruning was necessary if fruit quality was to be maintained. The very low light levels in the lower part of the canopy of these trees prior to harvest clearly supports this observation (Table 4). It is well known that 30% full sun is needed to saturate photosynthesis of apple leaves and to initiate flower buds. Although the differences were not always significant, it appears that dormant hedging resulted in the lowest light values, and summer hedging three times generally resulted in the highest levels. However, even this level was less than one-third than needed to saturate photosynthesis. It is clear from this information that these trees were allowed to get too dense and corrective hand thinning-out pruning was necessary.

In July 1981 the light status of these trees was evaluated by taking a fisheye photograph adjacent to a spur in the center bottom of each tree. Lakso (5) has reported these at percent sky values, which have a strong positive relationship to photosynthetic active radiation within the canopy. Using the regression of percent PAR with percent sky reported by Lakso (6), light levels ranged from 28.3 to 32.0% full sun. These values indicate an acceptable light condition in the canopies of these trees following the 3 years of annual dormant pruning.

The pruning treatments in this study had no influence on trunk circumference or change in trunk circumference, and after 5 years all trees had comparable canopy sizes. In addition to yield per tree, fruit quality as assessed by soluble solids, firmness, and russet was not influenced by the pruning treatments (data not pre-

**TABLE 2.—Influence of Timing of Summer Hedging on Fruit Size Distribution* of Golden Delicious on M26 after 4 and 5 Years of Treatment.**

| | 1980 Size Distribution (%) | | | | 1981 Size Distribution (%) | | | |
|---|---|---|---|---|---|---|---|---|
| Treatment | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Check (Hand, Dormant) | 52b† | 29ab | 19bc | 0.5 | 20ab | 33 | 48a | 2.5 |
| June, July | 40c | 36a | 25ab | 0.6 | 13b | 37 | 51ab | 1.9 |
| June, August | 37c | 31ab | 32a | 0.5 | 11b | 35 | 54a | 2.1 |
| July, August | 40bc | 33a | 26ab | 0.6 | 10b | 33 | 52ab | 2.7 |
| June, July, August | 40c | 34a | 23ab | 0.5 | 13b | 32 | 35b | 2.0 |
| Hedged, Dormant | 64a | 24b | 11c | 0.2 | 27a | 37 | 9c | 1.5 |

*Size 1 = 3 1/8" +; Size 2 = 2 7/8 to 3 1/16"; Size 3 = 2 1/4 to 2 3/4"; Size 4 = less than 2 1/4".

†Means without a letter in common are different at the 5% level (Duncan's multiple range test).

**TABLE 3.—Influence of Timing of Summer Hedging on Pruning Weights from Golden Delicious and Melrose Trees on M26 Rootstock.**

| | Pruning Weights (kg wt/Tree)* | | | | | |
|---|---|---|---|---|---|---|
| Cultivar | June | July | August | Dormant, Hedging | Hand Dormant | Total |
| 1977 | | | | | | |
| Golden Delicious | 1.45 | 0.43 | 0.27b | | | 2.15 |
| Melrose | 1.72 | 0.68 | 0.47a | | | 2.90 |
| 1978 | | | | | | |
| Golden Delicious | 0.52b† | 0.64b | 0.29b | 0.38 | 2.63b | 4.46b |
| Melrose | 0.73a | 1.02a | 0.44a | 0.51 | 5.85a | 8.55a |
| 1979 | | | | | | |
| Golden Delicious | 3.2 b | 1.5 | 0.3 b | 0.44 | 10.7 b | |
| Melrose | 4.0 | 1.8 | 0.7 a | 0.54 | 13.8 a | |
| 1980 | | | | | | |
| Golden Delicious | 2.89b | 1.72b | 1.99b | 0.52 | 10.1 b | 13.5 b |
| Melrose | 5.35a | 2.30a | 3.29a | 0.69 | 24.6 a | 30.2 a |
| 1981 | | | | | | |
| Golden Delicious | 2.26 | 2.35 | 1.02b | 0.40 | 9.79b | 12.7 b |
| Melrose | 2.18 | 2.82 | 1.56a | 0.49 | 15.16a | 18.5 a |

*In 1977 and 1978, dry weights are presented and in subsequent years, fresh weights.

†Means within a year with a different letter are different at the 5% level.

**TABLE 4.—Influence of Timing of Summer Hedging on Canopy Light Penetration in a North to South Transect Through the Tree at a Height of 100 cm.**

| | Percent Full Sun* | | | | | | Percent Sky‡ |
|---|---|---|---|---|---|---|---|
| Treatment | North | | Center | | South | Average | 1981 |
| Check (Hand, Dormant) | 2.6ab† | 4.4 | 2.5 | 5.8 | 7.5 | 4.6ab | 18.6 |
| June, July | 3.4a | 2.4 | 2.6 | 3.0 | 6.0 | 3.5b | 19.0 |
| June, July, August | 3.7a | 2.8 | 5.9 | 3.9 | 4.9 | 4.2b | 16.0 |
| July, August | 2.7ab | 2.4 | 2.2 | 6.9 | 3.2 | 3.5b | 19.1 |
| June, July, August | 3.1ab | 5.5 | 6.5 | 3.6 | 17.9 | 7.3a | 18.9 |
| Hedged, Dormant | 2.1b | 1.7 | 1.8 | 3.3 | 2.8 | 2.4b | 17.4 |
| Golden Delicious | 3.2a | 3.5 | 4.7 | 3.7 | 9.0 | 4.8 | 17.7 |
| Melrose | 2.6b | 3.0 | 2.5 | 5.1 | 5.2 | 3.7 | 18.7 |

*Percent full sun on bright, clear day, Sept. 17, 1979, reading at 50 cm intervals with a LiCor.

†Means without a letter in common are different at the 5% level (Duncan's multiple range test).

‡Determined by fisheye photography.

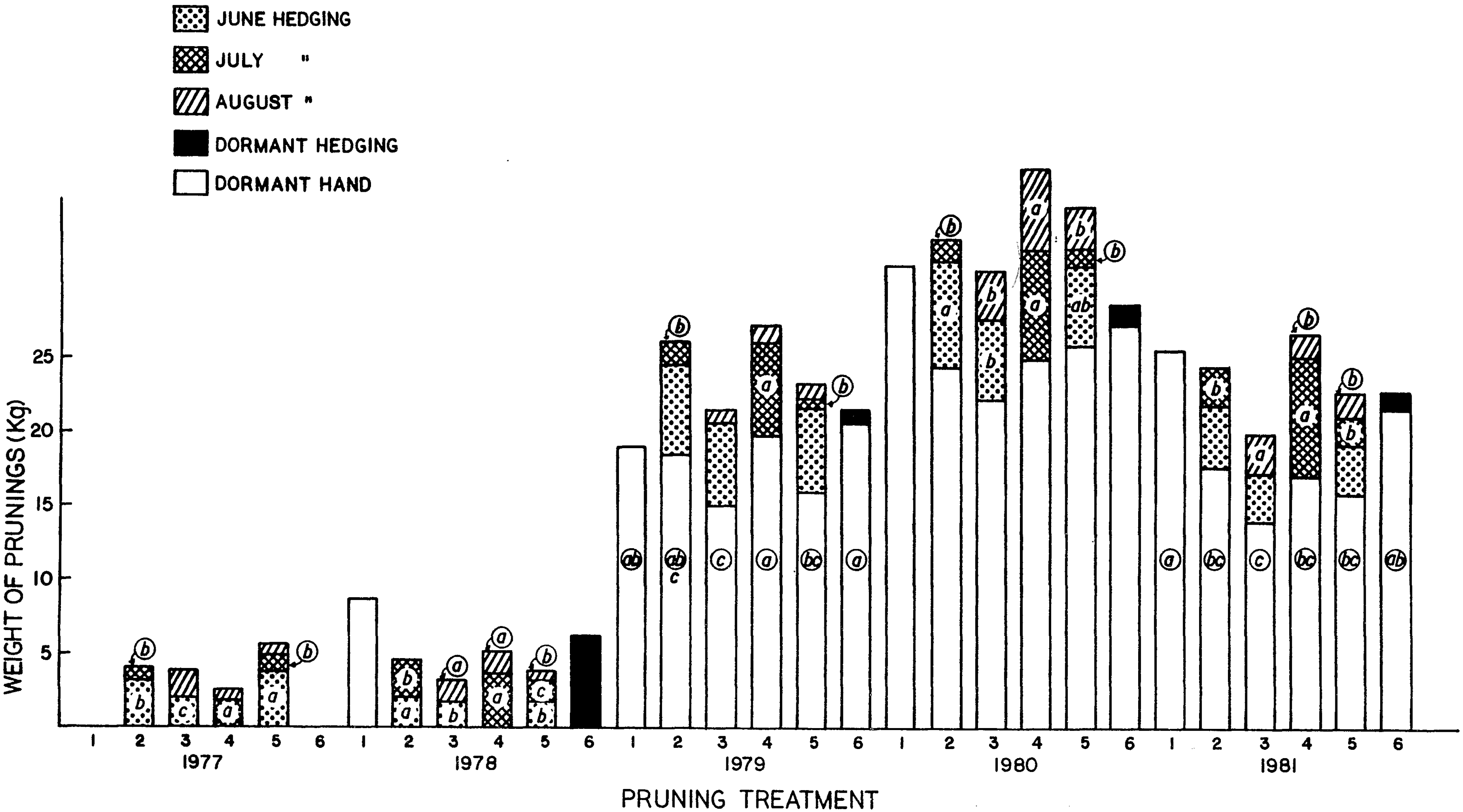


FIG. 1—Influence of timing of summer hedging on weight of prunings from apple trees (1977 and 1978, dry weights; 1979, 1980, 1981, fresh weights).

sented). Thus, mechanical summer hedging may be an acceptable method of efficiently containing canopy size. However, it must be recognized that fruit size may be reduced by summer hedging.

The time of summer hedging appeared to be of little consequence as long as the trees were hedged twice and hedging three times gave no additional advantage. If summer hedging is used, hand thinning-out pruning is also necessary. This is particularly important on red-fruited and vigorous growing cultivars, such as Melrose, which appear very sensitive to reduced light.

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# Response of Apple Shoots, Flowers, Fruit, and Roots to Heading-back Summer Pruning[1]

BRADLEY H. TAYLOR[2] and DAVID C. FERREE[3]

## INTRODUCTION

Summer pruning of apple trees has been studied for many years. However, there are contradictory reports on its effects. In the past researchers concluded that summer pruning reduced vegetative growth of apple trees (2, 8, 15, 18) and generally believed it removed new shoot growth, especially leaves, which used up "reserve foods" before those leaves could replace the reserves (8). However, summer pruning has also been reported to have no effect on shoot growth (3, 7) and in some cases it stimulated shoot growth (7, 12).

Summer pruning apple trees early in the growing season generally produced the same length of terminal shoots by the end of the season as dormant pruning or no pruning (1). Summer pruning later in the season resulted in 11-76% shorter terminal shoot length compared to dormant pruned or unpruned trees (1, 10, 15).

Summer pruning has also been reported to reduce flower density on apple trees (5, 10), but it sometimes increased the number of flowers occurring on vigorous shoots (14).

Summer pruning's effect on shoot vigor may influence other aspects of growth such as fruit set and subsequent fruit growth. Both shoots and fruits compete for photosynthates produced by the apple leaves (9), especially early in the season (18). Presence of terminal shoot leaves (potentially removed by summer pruning) later in the season increased fruit growth. Summer pruning has also been found to both increase (15, 17) and decrease (13) fruit quality. We previously reported that severe late summer pruning of young apple trees grown in pots drastically reduced the root system (19).

The results of many summer pruning experiments conflict with one another. The effects of summer pruning on the whole tree's physiology must be understood before it can be used reliably as a management tool in modern orchards. The following experiments were conducted to determine the effects of summer pruning on shoot, flower, fruit, and root growth of apple.

## MATERIALS AND METHODS

### Experiment 1

During March 1977, 9-year-old 'Red Prince Delicious'/M26 trees were selected for uniform vigor in an experimental orchard situated on a deep, fertile, Wooster silt loam soil. The trees had been trained to a central leader in a 3.66 x 6.10 m orchard spacing. Each tree was fertilized with 340, 650, and 800 g of ammonium nitrate in March of 1976, 1977, and 1978, respectively, with no fertilizer added in succeeding years of the experiment. All trees received standard pesticide applications.

Just prior to the initiation of this experiment, all trees were dormant pruned using moderate thinning-out cuts in March 1977. Each of five pruning treatments was applied in 1977, 1978, and 1979 to uniform, single, scaffold limbs on each single tree replicate. On terminals longer than 20 cm, two-thirds of the growth was pruned as follows: 1) previous season's growth at full bloom, 2) previous season's growth pruned 20 days after full bloom (AFB), 3) current season's growth pruned 40 days AFB, 4) current season's growth pruned in mid-July to mid-August after shoot elongation had ceased, and 5) unpruned control.

There were 18 replications in 1977 and 16 replications in succeeding years. Five random shoots in 1976 and 1977 and 10 random shoots in 1980 were measured during the dormant season. Basal circumference of each sample limb was measured annually during the dormant season. All flower clusters were counted in 1977 and 1978 on each limb. Fruit yield and size distribution on each limb were measured in 1980. Leaf N levels were determined by the macro-Kjeldahl method from 40 random mid-terminal leaf samples taken from each limb in late August 1977.

### Experiment 2

During August 1978, 10-year-old Anderson strain 'Jonathan'/M26 trees were selected for uniform vigor in the same experimental orchard described in Experiment 1. The trees were summer pruned by cutting off all terminal shoots > 10 cm each August of 1978 through 1981, and their response was compared to control trees which received only light annual dormant pruning with thinning-out cuts.

Additional cropping treatments were imposed on trees: 1) a horticulturally acceptable full crop, and 2) defruiting in June of 1979 and 1980. The treatments were arranged in a 2 x 2 factorial experiment with eight replications (20). Fresh weight of all shoots removed with summer pruning was measured in 1979 and 1980 and their leaf area and dry weight were calculated based on 2.3 kg (fresh weight) subsamples taken from two random trees in each cropping treatment. The spur leaf area per 'Jonathan' tree was estimated based on the measurements of tree canopy leaf area of 'Golden Delicious'/M26 reported by Ferree (4). It was assumed the average 'Jonathan'/M26 spur leaf area was similar to that of the 'Golden Delicious'/MM106 trees in August,

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[1]The authors gratefully acknowledge Ms. C. Holstead and Dr. G. Staby for the fruit ethylene analysis in the Dept. of Horticulture at The Ohio State University. Appreciation is also expressed to Dan, Doug, and John Taylor and Stephen Myers for donating their much needed technical assistance at critical times.

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since their canopy dimensions and vigor were similar. Estimated 'Jonathan'/M26 spur leaf area was calculated for trees with no crop:

$$\frac{125{,}000\ \text{cm}^2\ \text{av. 'Jonathan' canopy cross-section x}\ 10.1\ \text{cm}^2\ \text{av. 'Golden Delicious' spur leaf area}}{900\ \text{cm}^2\ \text{'Golden Delicious' canopy cross-section}}\ \text{x}$$

$$294\ \text{cm av. 'Jonathan' tree height} =$$

$$412{,}000\ \text{cm}^2\ \text{estimated spur leaf area per tree.}$$

Number of flower clusters per representative sample limb were counted on each tree in 1979, 1980, and in 1981 and 1982 when cropping treatments were not imposed on the trees. In 1979, trees were defruited chemically with a 20 ppm, dilute naphthaleneacetic acid (NAA) spray applied 15 days after full bloom when the largest fruit averaged 12 mm in diameter with subsequent hand-removal of remaining fruit. In 1980, fruit on no crop trees were removed by hand. Fruit set was counted after June drop on all flower count limbs in 1979, 1980, 1981, and 1982. In addition, in 1979 fruit set counts were made at two canopy depths where limbs and flowers were located: 1) in the outer 1 m of canopy (corresponding to limb location in the other years), and 2) at least 1 m inside the canopy periphery. The girth of 20 randomly selected and tagged fruit from each full crop tree was measured four times during 1980 and the net increase in diameter from the previous measurement was calculated.

Ethylene evolution was measured on five fruit picked at random from the outer 50 cm of the south side of each tree on Sept. 15, 22, and 29, 1980. Ethylene evolution rates were measured on one randomly selected fruit from each tree on the date of picking and during each of the 4 days thereafter. During this time, all sample fruit were held at 25° C. On the day of sampling, fruit were placed in capped (gas tight), 480-ml, wide-mouth glass jars for 1 hour. A 1-ml gas sample was injected into a Packard Model 417 gas chromatograph at 100° C with a 60 cm x 3 mm alumina-packed, stainless steel column at 85° C with flow rates of 300, 25, and 25 ml/minute, respectively, for air, $H_2$, and $N_2$ gas components. The flame ionization detector was operated at 140° C. Subsequently diameter, flesh firmness, and soluble solids of each fruit were measured.

Root samples from all trees were obtained from three columnar cores (11.4 cm in diameter x 50.0 cm deep) taken 1 m from the tree trunk at three randomly assigned vectors 120° apart on June 18, 1980. Roots were washed free of soil and lyophilized to dryness. Dry weights of both fine lateral feeder roots and all roots encountered were measured.

## RESULTS AND DISCUSSION

### Experiment 1

The 'Red Prince Delicious' limbs summer pruned at full bloom and 20 days AFB produced the same length of terminal shoots as the unpruned limbs (Table 1). However, limbs summer pruned 40 days AFB or in

**TABLE 1.—Effects of Time of Summer Pruning on Shoot Growth, Limb Circumference, Flower Clusters, and Cumulative Effects of 3 Years of Summer Pruning Treatments on Yield and Fruit Size of 'Red Prince Delicious' Sample Limbs.**

| | End-of-Season | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Terminal Shoot Length | Sample Limb Circumference (cm) | | | 1977 Leaf N | Flower Clusters per Limb | | Yield/cm Limb Circumference | Percent Marketable Fruit in 1980 in Size Categories (cm Diameter) | | | |
| Time of Pruning | 1977 (cm) | 1977 | 1979 | 1980 | (Percent Dry Wt) | 1977 | 1978 | 1980 | >8.0 | 8.0-7.3 | 7.3-5.7 | <5.7 |
| Full Bloom | 33.6a* | 13.6 | 16.7ab | 18.8ab | 1.87 | 219 | 182b | 1.3 | 71.6 | 14.0 | 8.1 | 0.0 |
| 20 Days AFB† | 32.7a | 13.0 | 15.2b | 17.0b | 1.88 | 203 | 176b | 2.0 | 68.6 | 15.9 | 9.0 | 0.1 |
| 40 Days AFB | 17.7b | 13.0 | 16.2ab | 19.2ab | 1.85 | 195 | 200b | 1.8 | 67.3 | 18.6 | 7.5 | 0.3 |
| Mid-July-August | 15.3b | 13.0 | 16.3ab | 18.4b | 1.95 | 199 | 180b | 1.7 | 64.4 | 20.1 | 9.2 | 0.0 |
| Unpruned Control | 30.8a | 13.6 | 18.1a | 21.3a | 1.91 | 210 | 250a | 1.7 | 64.8 | 15.6 | 12.7 | 0.6 |

*Mean separation within columns by Duncan's new multiple range test, 5% level where significant differences were found.
†After full bloom.

mid-July produced terminal shoots which were about one-half the length of those on unpruned limbs at the end of 1977. Aselage and Carlson (1) found average shoot regrowth on vigorous apple trees pruned in early summer was the same length as terminals on dormant pruned or unpruned trees, while terminals on trees pruned in July were 20% to 40% shorter than on unpruned control trees. Results of Myers and Ferree (15) revealed a trend of 10% to 40% shorter average terminal shoots on mature 'Red Prince Delicious'/M9 trees pruned in July as compared to dormant pruned trees and approximately a 60% reduction in average terminal shoot length on trees pruned in August or September. Our data supported by others (1, 5, 10) clearly indicate that early season summer pruning produces terminal shoots of the same vigor as dormant or no pruning, and pruning after mid-June to mid-July produces much less vigorous terminal shoots.

The generally reduced limb circumferences found on summer pruned trees in comparison to the unpruned controls (Table 1) suggest that limb vigor was reduced by summer pruning at all times. This is in contradiction with average terminal shoot length indications where later summer pruning was more devitalizing than early pruning. Our limb circumference results and those of others (10, 12, 20) suggest that limb or trunk circumference is not a meaningful indicator of the effect of summer pruning on tree vigor.

In 1977, summer pruning at all times reduced flower clusters per sample limb by approximately 25% as compared to the unpruned controls (Table 1). Similar results have been reported previously (5, 10, 11, 12). Miller (14) reported summer pruning of vigorous apple trees increased lateral flowering when a "stub" of the terminal shoot was left below the pruning cut, but it resulted in no increase in fruit set. Indeed, in our experiment, 3 years of summer pruning produced no effect on fruit yield or size distribution in 1980 (Table 1). Leaf nitrogen or yield efficiency were not influenced by the treatments.

## Experiment 2

August summer pruning induced approximately 70% to 80% shorter average terminals on these 'Jonathan'/M26 trees in comparison to dormant thinned controls (20). This is in contrast to the small effect on shoot growth of earlier pruning in Experiment 1. A large amount of leaves was removed with summer pruning (Table 2). It was calculated that approximately 50% of the whole tree leaf area was removed by pruning at a time when the leaf area was needed for fruit, shoot, and root growth. Presence of a fruit crop on trees pruned in

**TABLE 2.—Effects of Fruit Cropping on Terminal Shoots and Estimated Leaf Area Removed by Summer Pruning from 'Jonathan'/M26 Trees in August 1979 and 1980.**

| | | | Terminal Leaf Area in 1980 ($cm^2$) | | |
|---|---|---|---|---|---|
| | | | | Estimated | |
| | Fresh Wt of Shoots | | Measured per | | Percent of Whole |
| Cropping Treatment | 1979 | 1980 | kg Fresh Shoots* | Av./Tree | Tree Leaf Area† |
| Full | 15.6b‡ | 13.2b | 24,700 | 326,000 | 47 |
| None | 19.8a | 19.4a | 22,000 | 427,000 | 51 |

*Measured from 2.3 kg fresh weight bulk samples taken from two random trees from each cropping treatment.

†Percent of whole tree leaf area on terminal shoots at time of pruning was calculated based on the formula:

$$\text{percent tree leaf area on terminals} = \frac{\text{estimated shoot leaf area}}{\text{estimated shoot leaf area} + \text{estimated spur leaf area}} \times 100\%$$

‡Means significantly greater within columns at 5% level.

**TABLE 3.—Influence of Summer Pruning and Location of Sample Limb in Tree Canopy on Flowering and Fruit Set and Effect of Naphthaleneacetic Acid (NAA) Sprays* on Fruit Set of 'Jonathan'/M26 Trees in 1979.**

| | | | Fruit Set (%) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Flowering on Sample Limbs | | | | Outside 1m of Canopy | | | |
| | | Terminal Clusters as | 1m Inside Canopy | | Total/Cluster | | Total/ | Total/ Terminal |
| Pruning Treatment | Av. Flowers per Cluster | Percent of Total Clusters | No NAA | with NAA | No NAA | with NAA | Flower with NAA | Cluster with NAA |
| Summer | 2.0b† | 47a | 43.2a | 18.1b | 30.9 | 10.7a | 5.9a | 19.1 |
| Control | 2.9a | 19b | 38.5a | 5.5b | 26.8 | 4.6b | 1.6b | 18.2 |

*Trees were defruited by spraying 20 ppm NAA 15 days AFB when the largest fruit in cluster averaged 12 mm in diameter, with set counted 46 days after full bloom.

†Mean separation within indicated columns and rows by Duncan's new multiple range test, 5% level.

August 1978 and 1979 reduced the fresh weight of shoots removed by 21% and 32% in 1979 and 1980, respectively, as compared to trees without a fruit crop. Fresh weight of terminal shoots appeared more responsive to the effect of cropping than average terminal shoot lengths (20). Presence of a fruit crop reduced average terminal length only 13% in 1979, compared to trees with no fruit, and had no significant effect on comparable terminals in 1980.

Summer pruning the previous August reduced the number of flowers per cluster in 1979, but doubled the percentage of terminal clusters borne on spurs in comparison to control pruned trees (Table 3). The reduced potential photosynthate available to summer pruned trees in late summer may have reduced flower development.

The increased proportion of terminal clusters on sample limbs in the outermost 1 m of canopy in summer pruned trees appeared to reduce the effectiveness of NAA in chemical fruit thinning as measured by a 10.7% fruit set in comparison to a 4.9% set on controls. The low number of flowers per cluster on summer pruned trees did not appear related to their reduced susceptibility to NAA thinning because total fruit set per flower was also greater on summer pruned trees as compared to control trees sprayed with NAA.

Summer pruning's effect in reducing NAA's thinning activity seems largely due to the increased proportion of terminal flower clusters on summer pruned trees (Table 3). There was about twice the percentage of terminal clusters on summer pruned trees compared to control trees, and fruit set on summer pruned trees sprayed with NAA was about two times greater than on control trees with NAA applied. This conclusion is supported by the fact that pruning did not affect fruit set on terminal flower clusters. In addition, summer pruning did not influence the effect of NAA thinning on fruit found at least 1 m inside the canopy, which were borne exclusively on terminal flower clusters.

Summer pruning's effect on NAA thinning of fruit in 1979 encouraged us to investigate this phenomenon in more detail in 1981 and 1982. There was a significant interaction between pruning and NAA treatments at the 20 ppm NAA concentration, where summer pruning doubled fruit set on NAA-thinned trees in 1982 (Table 4). This result was very similar to the response measured in 1979 (Table 3). In 2 years (1979 and 1982) out of 3, summer pruning reduced the effectiveness of NAA in fruit thinning, coinciding with seasons of heavy fruit set on control trees not sprayed with NAA. Practically, these results suggest that when deciding on appropriate NAA rates for thinning, previous season's summer pruning practices need to be taken into account only during springs when conditions favor heavy fruit sets.

The trend of low fruit set on summer pruned trees sprayed with NAA in 1981 could have been due to their increased susceptibility to spring frosts occurring in 1981 because it was previously reported that summer pruning hastened flowering by a few days (20). This aspect needs further investigation but would caution

**TABLE 4.—Influence of Summer Pruning and Four Concentrations of Naphthaleneacetic Acid (NAA) Sprays on Fruit Thinning of 'Jonathan'/M26 Apple Trees.**

| Concentration NAA (ppm) | Percent Set | | Average Fruit Wt (g) | | Seeds/Fruit | | Percent Set in 1980 on Trees Pruned | | Pruning/NAA-Interaction as Percent Set | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 1981 | | 1982 | |
| | 1981 | 1982 | 1981 | 1982 | 1981 | 1982 | Control | Summer | Control | Summer | Control | Summer |
| 0 | 17.1a* | 50a | 150 | 117 | 5.6 | 7.0a | 26.9 | 26.8 | 18.9 | 15.3 | 54a | 46a |
| 5 | 7.0b | 28b | 155 | 121 | 5.2 | 6.8ab | | | 8.5 | 5.5 | 29b | 27bc |
| 10 | 4.3bc | 23b | 147 | 124 | 4.9 | 6.5bc | | | 5.1 | 3.6 | 24bc | 23bc |
| 20 | 2.6c | 14c | 157 | 119 | 5.0 | 6.3c | | | 4.5 | 0.7 | 9d | 18c |
| Pruning | | | | | | | | | | | | |
| Control | 9.2a | 29 | 152 | 120 | 5.0 | 6.6 | | | | | | |
| Summer | 6.3b | 29 | 152 | 121 | 5.4 | 6.6 | | | | | | |

*Means separated by Duncan's new multiple range test, 5% level where significant differences were found.

against heavy summer pruning on frost sensitive trees growing on poor sites. Over a 4-year period, summer pruning had no effect on fruit set as measured on sample limbs on trees not sprayed with NAA (Table 3 and 4).

In 1980, fruit on summer pruned trees were consistently larger than on control trees throughout the season (Table 5). Also, the net increase in fruit diameter on summer pruned trees from June 22 to July 24 was greater than on controls. This response was probably due to the previously reported trend of lower fruit density in summer pruned trees (3.24 compared to 3.57 kg fruit/$m^3$ tree canopy volume, respectively) in comparison to control trees (20). During the time period after summer pruning until harvest, the net increase in fruit size on summer pruned trees was actually an average of 0.1 cm smaller than controls (Table 5).

Under ideal conditions, apple fruits continue to increase in size linearly from late August until harvest (6). These results and the results of Marini (12, 13) suggest that summer pruning exerts its greatest effect on fruit size during the season of summer pruning and not in the succeeding season. This was probably due to the drastically decreased photosynthate production potential after pruning (Table 2). Therefore, in a year when fruit size is expected to be large, summer pruning would not be expected to adversely affect fruit size.

Maturing fruits on summer pruned trees sampled from the south side of the outer 50 cm of tree canopy had higher rates of ethylene evolution when compared to control trees during the 3-week period before harvest in 1980 (Table 5). These higher rates provided some evidence that summer pruning hastened maturity of the apple fruit. Evidence from other research indicated that summer pruning altered the physiology of other processes in apple: leaf photosynthesis, transpiration and leaf senescence (19), and time of flowering (20). However, hastened time of flowering may be partially explained by the increased proportion of terminal flowers on summer pruned trees. Indeed, the other apple fruit maturity factors, soluble solids and flesh firmness, were not affected by summer pruning (Table 5).

There were no statistically significant pruning or cropping effects on root samples under 'Jonathan'/M26 trees (Table 6). The trends in the lateral feeder root data suggest that presence of a fruit crop may have a suppressing effect on root growth, while summer pruning may not affect root growth on mature cropping trees. This contrasts with the 50% reduction in root dry

**TABLE 5.—Effects of Summer Pruning on Growth Rate and Maturity of Selected Fruit Samples on 'Jonathan'/M26 Trees in 1980.**

| Pruning Treatment | Fruit Diameter (cm) | | | |
|---|---|---|---|---|
| | 22 June | 24 July | 25 August | 7 October |
| Summer | 2.95a* | 4.88a | 6.55a | 7.23a |
| Control | 2.81b | 4.59b | 6.16b | 6.95b |
| | Net Increase from Previous Date | | | |
| Summer | — | 1.92a | 1.67 | .683a |
| Control | — | 1.78b | 1.56 | .795a |
| | Fruit Maturity Factors During 3 Weeks Prior to Harvest | | | |
| | Ethylene (nl $hr^{-1}$ $kg^{-1}$)† | Fruit Size (g) | Soluble Solids (%) | Flesh Firmness ($kg/cm^2$) |
| Summer | 6,668 | 146 | 11.53 | 17.19 |
| Control | 6,045 | 141 | 11.50 | 16.87 |

*Mean separation within columns by Duncan's new multiple range test, 5% level.
†Analysis of variance was perfomed on ethylene evolution data (nl $hr^{-1}$ $kg^{-1}$ fruit) transformed to natural logarithms in order to achieve linearity for valid mean comparisons.

**TABLE 6.—Effects of 2 Years of Summer Pruning and 1 Year of Fruit Cropping Treatments on Dry Weight of Root Samples from 'Jonathan'/M26 Trees on June 18, 1980.**

| Treatment | | Root Dry Weight (g) | |
|---|---|---|---|
| Pruning | Cropping | Lateral Feeders | Total Encountered |
| Summer | Full | 2.80* | 4.57 |
| | None | 3.52 | 10.52 |
| Control | Full | 2.77 | 4.83 |
| | None | 3.72 | 5.52 |

*Not statistically significant.

weights we found on summer pruned, young, container-grown apple trees (19). However, the frequently reported (10, 12, 13, 20) pronounced effect of a fruit crop in reducing tree trunk growth in comparison to summer pruning's minimal effect, would support the conclusions we draw from our root data for mature trees (Table 6).

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# A Comparison of the Influence of Summer Pruning at Two Dates on the Growth and Development of Young Apple and Peach Trees

**CURT R. ROM and DAVID C. FERREE**[1]

## INTRODUCTION

Summer pruning has been used as a means of controlling vegetative growth in apple (1, 6) and peach trees (9). However, the responses to similar summer pruning treatments may vary due to differences in growth habit. Summer pruning effects have been evaluated in several studies of mature apple trees (1, 6, 7) and simulated summer hedging of mature peach trees (8, 9). Young potted trees are often used in order to study the effects of pruning treatments on physiological activity, carbon allocation, carbohydrate fractions, and plant growth and development (7, 8, 10, 13). These reports are often cross-referenced; however, it is difficult to make direct comparisons between studies and crops because of differences in treatment parameters and growth conditions. Such information would be valuable in understanding the influence of this cultural practice.

This study compares the effects of similar summer pruning treatments at two dates on young apple and peach trees.

## MATERIALS AND METHODS

One-year-old trees of 'Redhaven'/'Halford' peach and MM106 apple were planted in 2.9 liter pots containing a Wooster silt loam, peatmoss, and perlite medium (1:1:1, v/v). Trees received 15 grams of a 14.0 N-6.1 P-11.6 K Osmocote fertilizer with additional application of approximately 1 liter of 10 g/l 20.0 N-8.7 P-16.6 K liquid fertilizer added at 3-week intervals with watering. At planting, trees were pruned at the third node above the bud union on peaches and above the soil line on apples, with the lowest emerging shoot selected and trained upright as a single shoot. Plants were grown outdoors and after 60 days of growth peaches averaged 65 cm height and apples averaged 47 cm height. Experiments were terminated after 125 days of growth.

Time of pruning treatments consisted of: 1) unpruned control, 2) pruned at 60 days, and 3) pruned at 90 days. Pruning removed 50% shoot length at time of treatment. Trees were arranged by height into a randomized complete block design with nine replications for peaches and eight replications for apple. Plant material harvested at each pruning and at the experiment termination was force-air dried at 70° C. Net photosynthesis (Pn) and transpiration (Tr) were measured on the third or fourth intact leaf below the pruning cut and a corresponding leaf on unpruned plants at 10 and 24 days after the 90-day pruning treatment. Pn was measured with an infrared gas analyzer and Tr was measured with a dew point hygrometer. Photosynthetically active radiation at Pn saturation levels of 1050 $\mu Em^{-2}s^{-1}$ for peach and 900 $\mu Em^{-2}s^{-1}$ for apple inside the leaf chamber was emitted by phosphorus-coated metal arc lamps. Leaf chamber temperatures of 32° ± 2° C and air flow rates of 3 l $m^{-1}$ were maintained.

## RESULTS AND DISCUSSION

Summer pruning resulted in increased Pn rates of apple and peach (40% and 18%, respectively) compared to unpruned controls (Table 1). Increased Pn occurred within 10 days after treatment and was maintained for 24 days after treatment. Leaves were more than 40 days old at the time of Pn measurement. Sams and Flore (11) reported that cherry leaves reached maximum Pn within 30 days after unfolding and were approximately

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**TABLE 1.—Influence of Summer Pruning Late in the Season on Pn and Tr of Young Apple and Peach Leaves.***

| Treatment | Net Photosynthesis ($mgCO_2dm^{-2}hr^{-1}$) Days After Treatment 10 | 24 | Transpiration ($g\ H_2O\ dm^{-2}hr^{-1}$) Days After Treatment 10 | 24 |
|---|---|---|---|---|
| | | **Apple** | | |
| Control | 15.4b | 13.5b | 1.6b | 2.3b |
| Pruned† | 25.6a | 24.2a | 2.5a | 2.9a |
| | | **Peach** | | |
| Control | 24.8b | 18.2b | 2.1b | 1.9b |
| Pruned | 30.0a | 27.9a | 2.5a | 2.8a |

*Mean separation within date and tree type by Duncan's new multiple range test, 5% level.
†Trees pruned after 90 days' growth.

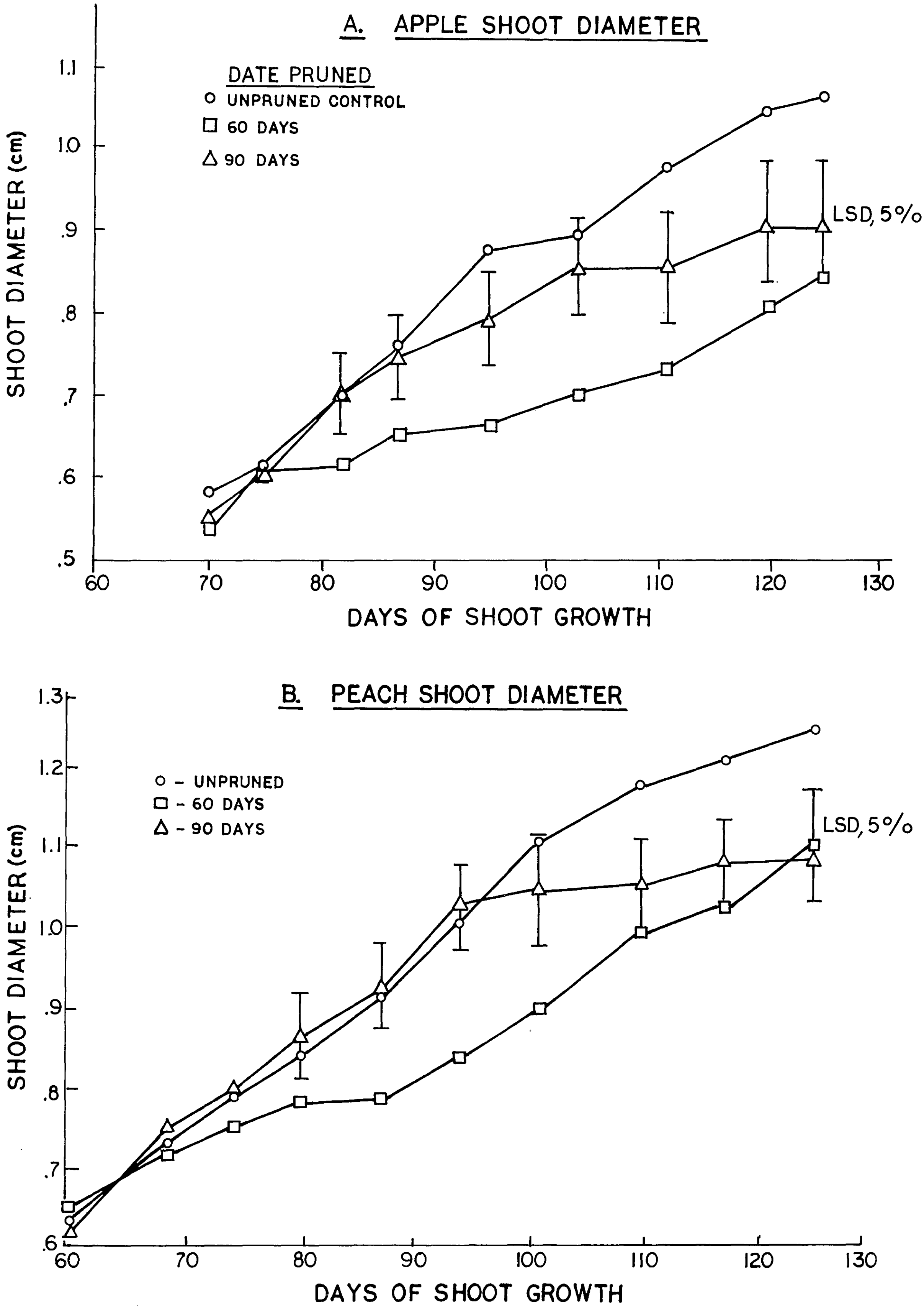


FIG. 1—Influence of time of summer pruning on main shoot diameter of: A) young 'MM106' apple, and B) 'Redhaven' peach trees.

**TABLE 2.—Influence of Time of Pruning on Shoot Growth and Leaf Development of Young Apple and Peach Trees.***

| Time of Pruning Treatment | Shoot Growth | | | | | Leaves at Harvest | | | | Total Leaves† | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Diameter (cm) | Length (cm) | Lateral Shoot No. | Lateral Shoot Length | Total Length | No. | Area ($cm^2$) | Size ($cm^2$) | SLW ($mgcm^{-2}$) | No. | Area ($cm^2$) |
| | | | | | Apple | | | | | | |
| Control | 1.06a | 108.1a | .4b | 4.1c | 115.3b | 63.4b | 2480a | 39.5a | 10.8a | 63.4b | 2480a |
| 60‡ | .84b | 79.4b | 2.3a | 43.0a | 172.3a | 89.0a | 1985b | 23.8b | 7.7c | 101.6a | 2368a |
| 90 | .91b | 57.0c | 1.4ab | 14.1b | 76.8c | 47.3b | 867c | 18.1b | 9.0b | 63.3b | 1746b |
| | | | | | Peach | | | | | | |
| Control | 1.26a | 126.9a | 2.6b | 30.1a | 201.3b | 107.6b | 4393a | 45.9a | 7.6b | 107.6b | 4393a |
| 60 | 1.11b | 74.8b | 9.3a | 24.1b | 263.9a | 150.1a | 4549a | 31.2b | 6.7c | 162.9a | 5172a |
| 90 | 1.10b | 61.1c | 3.5b | 16.4c | 101.8c | 56.3c | 1493b | 27.9b | 8.0a | 88.4b | 3401b |

*Mean separation within columns and tree type by Duncan's new multiple range test, 5% level.
†Total = on plant at harvest + leaves removed by pruning.
‡Days of shoot growth at time of pruning.

20% below maximum by 50 days. Heinicke and Hoffman (3) observed a downward trend in Pn of young apple tree leaves late in the season (July-October). Therefore, leaves of control plants appeared to be in a state of decline or senescence at the time of pruning, but the pruning treatment increased Pn to presumably maximal levels. Likewise, Taylor (13) reported a 36% increase in apple leaf Pn after 75% shoot removal. Although the response of apple and peach were similar in the present study, differences in magnitude may reflect either differences in leaf age or rates of senescence, which may be species-dependent.

Transpiration of leaves on pruned plants was also increased compared to controls within 10 days, and at 24 days after treatment (Table 1). Transpiration rate may be limited by stomatal ($R_s$) or residual resistances ($R_r$). $R_s$, the major transpirational control, was not affected by summer pruning of young mulberry trees; however, $R_r$ was reduced (12). $R_s$ was decreased after summer pruning young apple trees (7). In the present study, plants were well watered, Pn was determined after leaves were in the cuvette for 10-20 minutes allowing adequate adaptation with minimum leaf stress, and there was no declining trend in control plant Tr during the experiment. Therefore, this may indicate possible consistent $R_s$ and changes in $R_r$ components. Kriedman (4) noted that these $R_r$ can also be rate limiting to $CO_2$ assimilation. However, changes in stomatal responsiveness after summer pruning cannot be discredited (7,13).

Shoot diameter and length of apple and peach were reduced by summer pruning (Table 2). Shoot diameter was similarly reduced by pruning at either date, a 10-20% reduction. Pruning caused a depression in growth rate as indicated by a reduction in diameter increase apparent 10-20 days after treatment (Fig. 1). Although growth rates were decreased after the 60-day pruning treatment, the rates were similar to control within 30 days. Plants pruned at 90 days had decreased growth rate after treatment and throughout the remainder of the experiment.

Shoot length was decreased by both pruning treatments, with the greatest reduction from pruning at 90 days (Table 2). Pruning at 60 days resulted in an increase in lateral shoot number formed from axial bud break, while pruning at 90 days resulted in a mixed response. Lateral shoots of apple trees formed after summer pruning were longer than laterals of controls, while lateral shoots of pruned peach trees were shorter. This indicates a strong apical dominance of apple and less apical control in peaches. Also, in peaches, four times more lateral branches were formed on trees pruned at 60 days than controls or pruned apples. This indicates that although early summer pruning of peach may cause vigorous lateral shoot development, the vigor of individual shoots is reduced. Pruning at 60 days resulted in increased total shoot length and pruning at 90 days had reduced total shoot length for both crops.

Leaf number at harvest and total leaf number were increased by pruning at 60 days due to the regrowth

**TABLE 3.—Influence of Time of Summer Pruning on Dry Weight Accumulation of Young Apple and Peach Trees.***

| Time of Pruning Treatment | Plant Dry Wt. at Harvest (g) | | | | Shoot:Root† | Total Dry Wt. Accumulation (g)‡ | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Leaves | Shoots | Roots | Total | | Leaves | Shoots | Roots | Total |
| | | | | Apple | | | | | |
| Control | 26.6a | 34.4a | 17.9a | 78.9a | 3.4a | 26.6a | 34.4a | 17.9a | 78.9a |
| 60** | 15.3b | 18.4b | 10.8b | 44.6b | 3.2a | 17.8b | 19.5b | 10.8b | 48.1b |
| 90 | 7.6c | 14.7b | 12.5b | 34.9b | 1.8b | 15.5b | 18.3b | 12.5b | 46.3b |
| | | | | Peach | | | | | |
| Control | 35.5a | 44.8a | 56.2a | 136.5a | 1.4a | 35.5a | 44.8a | 56.2a | 136.5a |
| 60 | 30.5b | 27.3b | 46.2b | 104.1b | 1.3a | 34.1a | 28.7b | 46.2b | 109.0b |
| 90 | 11.8c | 22.4c | 42.4c | 76.6c | .8b | 24.9b | 28.4b | 42.4b | 95.7b |

*Mean separation within columns and tree type by Duncan's new multiple range test, 5% level.
†Shoot:root ratio = shoot + leaf dry weight ÷ root dry weight.
‡Total dry weight accumulation = harvest dry weight + tissue removed by pruning.
**Days of shoot growth at time of pruning.

(Table 2). The increase in leaf number resulted in leaf area similar to controls for peach but not for apple. Pruning at 90 days reduced leaf area. Leaf size was reduced by pruning at either date. Specific leaf-weight (SLW) was reduced by pruning at 60 days. The reduction in SLW reflects the increase in leaf number from regrowth. Regrowth leaves may be morphologically different and were younger.

Summer pruning reduced dry weight accumulation in all plant parts and total dry weight accumulation (harvest + tissue removed by pruning) of both apple and peach (Table 3). Summer pruning reduced total apple dry weight more than peach (average of treatments = 49.5% and 34%, respectively). Pruning at 90 days resulted in greater reduction of total dry weight of peach than pruning at 60 days. In apple, a similar trend existed but differences were not significant.

Time of pruning affects dry weight of various plant parts differently (Table 3). Pruning at 60 days resulted in shoots having the greatest percent reduction of control (47% for apple, 39% for peach). However, pruning at 90 days resulted in leaf dry weight having the greatest reduction (71% for apple, 67% for peach). Generally, roots were the least influenced by summer pruning (35% and 25% less than control for apple and peach, respectively). Pruning early in the season tended to influence apple root dry weight more than pruning later, but the converse was true for peaches. This difference in response may be due to differences in periodicity of root growth of the two crops. Root growth of young peaches had the greatest incremental increase between 90 and 125 days of growth (10).

Pruning at 90 days reduced the shoot-to-root ratio (Table 3). It has been reported that shoot and root growth may have a functional equilibrium (2, 10). Pruning immediately alters this relationship but a balance of growth is re-established. In our study, this was observed on plants pruned at 60 days, which had shoot-to-root ratios similar to controls 65 days following pruning. Plants pruned at 90 days had minimal shoot and leaf regrowth (Table 2), and therefore a smaller shoot-to-root ratio. If the experimental period after late pruning had been extended, the ratio may have also increased.

Summer pruning resulted in increased Pn rates (Table 1) and early pruning resulted in regrowth with leaf area similar to controls (Table 2). These factors were not able to compensate for the tissue removed and the depression in growth rates caused by pruning treatments. In addition to the tissue removed by summer pruning, dark respiration was increased (7) and a greater proportion of carbohydrates utilized. Thus, plant dry weight and total dry weight accumulation were reduced by pruning.

This study has demonstrated that apple and peach have some common responses to summer pruning treatments. However, the magnitude of response may vary due to the species-dependent growth habit. In both cases, summer pruning increased physiological activity of Pn and Tr of older leaves. Pruning early in the season resulted in more regrowth than pruning later and peaches tended to have more lateral shoot regrowth and leaf development. Both pruning treatments resulted in reduced growth; however, 50% shoot removal appeared to reduce growth of apple more than peach.

Pruning tended to reduce growth of shoot fractions the most and root growth the least. Since a functional equilibrium may be established between root and shoot growth, the "dwarfing" capacity of summer pruning may not occur and the potential for growth the following year would not be altered. This is the case for mature apple (6) and peach (9) trees. Growers who manage a diversity of fruit crops should be aware of crop dependent growth responses to similar cultural practices.

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# The Influence of Three Tree Training Systems within Hedgerows on Light Distribution, Cropping, and Efficiency of 'Redhaven' and 'Redskin' Peaches

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## INTRODUCTION

As the cost of production increases, commercial peach growers become more concerned with orchard efficiency. Peach trees are relatively short-lived. Thus, any practice which encourages early crop production becomes especially important. Therefore, new tree training systems have been developed and planting densities increased (2, 5, 6).

Currently there is a lack of adaptable and sufficiently dwarfing peach rootstocks. To control tree size in high density hedgerows, mechanical hedging during the growing season has been recommended (2, 6). However, it has been reported that summer pruning can lead to decreased light penetration due to dense regrowth on the canopy periphery (3). Although previous studies have evaluated the influence of canopy shape on cropping and yield (1, 5, 6), or evaluated effects of training systems on light penetration within the canopy (1, 3), there is little information relating tree training, light, yield, and yield efficiency.

This study was established to determine the influence of tree training systems within mechanically summer pruned hedgerows on light distribution, cropping, and growth of two peach cultivars.

## MATERIALS AND METHODS

### General

'Redhaven' and 'Redskin' on 'Siberian C' rootstock peach trees spaced 3.1 x 3.7 m in north/south rows were planted at the OARDC Horticultural Research Unit 2 in 1977. Trees were developed into hedgerows with one of the following training systems: 1) vase — conventional open center; 2) palmette fan with 4-6 scaffolds; or 3) natural — untrained. Eight randomized blocks of ten tree plots were used. Blocks were split-plot for cultivar. Adjacent blocks were separated by two guard trees.

### Pruning and Training

Trees were trained into appropriate forms after the first growing season. Thereafter, tree structure was maintained by conventional dormant pruning except for the natural system, which received only minimal dormant pruning (removal of dead wood and low hanging branches). Trees were summer hedged on sides and tops with a sickle-type mower mounted on a tractor. Hedging was usually done during the third week of June and again the third week of July with the exception of 1982, when trees were only hedged in late July. Canopy width for fan and natural systems was 1.5 m and 2 m for the vase system. All trees were maintained at a height of 2.5 m.

### Cropping

Trees produced the first economic crop in 1980, the third growing season. Late spring frosts resulted in only a partial crop in 1981. There was no crop in 1982 after severe low winter temperatures (7). A light crop was produced in 1983. In cropping years, fruit was harvested with a 2 to 4 day frequency and the marketable and cull fruits for each tree were weighed.

During 'Redskin' harvest in 1980, 10 replicate 'Redskin' trees of each system were divided into thirds by height, width, and depth to form 27 equal tree sections. Fruit number within each section was counted and fruit color was rated on a scale of 1 = poor color to 5 = good color. Percent full sun (% FS) was measured at harvest with a Li-Cor radiometer with a PAR (400-660 nm) quantum sensor within each section. Days during which light readings were made were hazy or light-overcast to reduce sunflecks and shadows.

In 1981, % FS was measured in 10 replicate 'Redskin' trees of each training system. Trees were divided into quadrants by one-half canopy width and depth and PAR quantum sensors with integrators were placed in the center of each quadrant at one-half canopy height. Percent full sun was measured before and after July hedging.

Trunk circumference was measured annually approximately 30 cm from the soil line.

## RESULTS AND DISCUSSION

### Percent Full Sun

The natural training system had the highest average % FS compared to the vase or fan training systems at harvest in 1980 (Table 1). This is probably attributed to the distribution of growth throughout the entire natural canopy, whereas the vase and fan tend to have more vegetative growth in the tops of the trees. This is indicated by the fact that % FS in the top third of the canopy sections of natural trees was 24-29% higher than that of the vase or fan. Also, within the natural canopy, several small "twiggy" shoots were produced in the central portion of the tree and these tend to die annually. Thus, the north and south center sections of the natural trees tended to have higher average % FS than other systems. In all canopies, light decreased from the top to the bottom of the tree and from the sides (E or W) to the center of the tree.

Light was measured at a mid-canopy location in 1981 because the majority of the 1980 crop was located there. There was no difference in light penetration between

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training system, canopy position, tree side, and before and after July hedging (Table 2). Hedging increased light penetration by only about 2% full sun. This was similar to 1980 light measurements where there was no difference in percent full sun at a mid-canopy location between any training system (Table 1). Likewise, Kappel and Flore (3) have reported that there is little difference in light penetration between different peach training system canopies and hedging only improved the light microclimate in the top 25 cm of hedgerows.

## Yield

In 1980 and 1983, both 'Redhaven' and 'Redskin' yields were greatest for trees in the natural system, and there was no yield difference between the open center and vase training systems (Table 3). Natural trained trees produced the largest weight of cull fruits in 1980 and 1983. On a percent of total yield basis, there was essentially no difference between systems (average percent culls: vase = 14%; fan = 14%; natural = 15%).

**TABLE 1.—Influence of Three Hedgerow Tree Training Systems on Light Penetration and Distribution in 3-Year-Old 'Redskin' Peach Trees.***

| | Percent Full Sun | | | |
|---|---|---|---|---|
| | Training System† | | | |
| Location | Vase | Fan | Natural | Average |
| Average | 33.9b | 31.8b | 41.2a | 35.6 |
| | | Canopy Height | | |
| Top | 65.4 | 62.7 | 80.9 | 69.7a |
| Mid | 23.0 | 21.5 | 28.2 | 24.2b |
| Bottom | 13.3 | 11.3 | 14.5 | 13.0c |
| | | Canopy Section | | |
| NE | 30.3 | 25.9 | 43.1 | 33.1cde |
| E | 31.3 | 24.2 | 33.7 | 29.7cd |
| SE | 41.4 | 32.5 | 44.3 | 39.4bc |
| NC | 24.2 | 24.3 | 32.9 | 27.1e |
| C | 33.1 | 21.0 | 24.0 | 26.1e |
| SC | 31.5 | 19.6 | 38.0 | 29.7ed |
| NW | 35.2 | 34.3 | 45.5 | 38.3bcd |
| W | 29.4 | 49.4 | 55.2 | 44.7ab |
| SW | 48.6 | 55.4 | 53.7 | 52.6a |

*Mean separation by Duncan's new multiple range test, 5% level.
†N.S. = no significance.

**TABLE 2.—Influence of Three Hedgerow Tree Training Systems on Light Penetration and Distribution of 4-Year-Old 'Redskin' Peaches, 1981.**

| | Percent Full Sun* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Before Hedging | | | | After Hedging | | | |
| | Training System | | | | Training System | | | |
| | Vase | Fan | Natural | Average | Vase | Fan | Natural | Average |
| Average | 15.7 | 15.7 | 21.6 | 17.6 | 17.4 | 16.5 | 23.3 | 19.0 |
| **Canopy Position** | | | | | | | | |
| NE | 14.8 | 20.0 | 23.6 | 19.5 | 19.0 | 17.8 | 23.4 | 20.0 |
| SE | 14.0 | 12.6 | 19.6 | 15.4 | 17.8 | 13.6 | 22.8 | 18.1 |
| NW | 20.6 | 14.4 | 21.2 | 18.7 | 20.8 | 14.0 | 23.6 | 19.5 |
| SW | 13.2 | 15.6 | 21.8 | 16.9 | 11.8 | 20.8 | 23.2 | 18.6 |
| **Tree Side** | | | | | | | | |
| East | 14.4 | 16.3 | 21.6 | 17.5 | 18.4 | 15.7 | 23.1 | 19.1 |
| West | 17.9 | 15.0 | 21.5 | 17.8 | 16.3 | 12.4 | 23.4 | 19.1 |

*N.S. = no significant difference by Duncan's new multiple range test, 5% level.

In 1980, 'Redskin' trees in the natural system had more fruit than either the vase or fan (Table 4). The most fruit were in the mid-third of the tree, with the least in the top. Likewise, the greatest proportion of fruit was in the center sections.

Fruit color of 'Redskin' fruit from natural system trees was better than that of either the vase or fan systems (Table 4). Fruit color was best in the top third of the tree and decreased down the canopy. Likewise, fruit color was poorest in the center of the trees, compared to either east or west sections. Fruit color was significantly correlated to % FS (Table 1) at harvest ($R^2 = .72$).

## East-West Tree Sides

North/south hedgerow orientation increases light interception (1, 4) and results in more uniform bearing from both sides of the hedgerow wall (4). However, in our orchard, several differences between the east and

**TABLE 3.—Influence of Three Hedgerow Tree Training Systems on Yield of 'Redhaven' and 'Redskin' Peaches in 1980 and 1983.***

| | 1980 Yield (lb) | | | 1983 Yield (lb) | | |
|---|---|---|---|---|---|---|
| | Training System | | | Training System | | |
| Fruit Grade | Vase | Fan | Natural | Vase | Fan | Natural |
| | | | Redhaven | | | |
| Marketable | 56.6b | 56.9b | 67.6a | 20.0b | 17.5b | 27.8a |
| Culls | 8.4c | 9.5b | 12.6a | 3.7b | 3.5b | 5.8a |
| Total Yield | 64.9b | 66.3b | 80.2a | 23.7b | 20.6b | 33.2a |
| | | | Redskin | | | |
| Marketable | 45.5b | 45.0b | 54.6a | 8.3b | 10.5b | 18.5a |
| Culls | 8.7a | 6.9b | 8.5a | 1.2b | 1.6b | 3.0a |
| Total Yield | 54.1b | 51.8b | 63.0a | 9.5b | 12.1b | 20.6a |
| | | | Average | | | |
| Marketable | 51.0b | 50.9b | 61.1a | 14.1b | 14.0b | 23.1a |
| Culls | 8.5b | 8.2b | 10.6a | 2.5b | 2.6b | 4.4a |
| Total Yield | 59.1b | 59.5b | 71.6a | 14.9b | 15.6b | 25.18a |

*Mean separation within rows and years by Duncan's new multiple range test, 5% level.

**TABLE 4.—Influence of Tree Training Systems within Hedgerows on Fruit Number, Yield Distribution, and Color of 3-Year-Old 'Redskin' Peach Trees, 1980.***

| | | 1980—Yield Canopy Position | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Training System | Total | NE | E | SE | NC | C | SC | NW | W | SW |
| | | | | | | Fruit Number | | | | |
| Vase | 69.9b | 7.8c-k | 11.8c-h | 6.4e-k | 13.8b-e | 4.1h-k | 14.8bc | 2.1ijk | 6.8d-k | 2.2ijk |
| Fan | 67.0b | 4.5g-k | 8.4c-j | 6.6e-k | 8.3c-k | 12.3c-g | 15.3bc | 4.7g-k | 5.8f-k | 1.1jk |
| Natural | 97.5a | 11.1c-h | 20.3ab | 8.9c-i | 14.5bcd | 24.1a | 13.3b | 0.5k | 4.2h-k | 0.8jk |
| Average | 78.1 | 7.8b | 13.5a | 7.3b | 12.2a | 13.5a | 14.5a | 2.4d | 5.6c | 1.4d |
| **Canopy Location** | | | | | | | | | | |
| Top | 44.2c | | | | | | | | | |
| Middle | 107.6a | | | | | | | | | |
| Bottom | 79.8b | | | | | | | | | |
| | | | | | | Fruit Color | | | | |
| **Training System** | | | | | | | | | | |
| Vase | 2.57b | | | | | | | | | |
| Fan | 2.42c | | | | | | | | | |
| Natural | 2.86a | | | | | | | | | |
| Average | 2.62 | 2.58ab | 2.75ab | 2.75ab | 2.48b | 2.41b | 2.53b | 2.61ab | 2.71ab | 2.80a |
| **Canopy Location** | | | | | | | | | | |
| Top | 2.86a | | | | | | | | | |
| Middle | 2.54b | | | | | | | | | |
| Bottom | 2.44b | | | | | | | | | |

*Mean separation by Duncan's new multiple range test, 5% level.

TABLE 5.—Influence of Tree Training Systems within Hedgerows on Trunk Cross-sectional Area and Yield Efficiency of 'Redhaven' and 'Redskin' Peaches.*

| Training System | Trunk Cross-sectional Area ($cm^2$) Tree Age (years) 2 | 3† | 4 | 5‡ | 6† | Yield Efficiency lb/x-sect. 6 yr |
|---|---|---|---|---|---|---|
| | | | | **Redhaven** | | |
| Vase | 37.0 | 62.0 | 87.6 | 117.4 | 137.0 | 0.152 |
| Fan | 38.0 | 58.9 | 82.2 | 107.6 | 127.6 | 0.152 |
| Natural | 37.5 | 60.5 | 85.3 | 112.2 | 125.1 | 0.219 |
| | | | | **Redskin** | | |
| Vase | 36.5 | 64.1 | 91.5 | 121.1 | 148.1 | 0.057 |
| Fan | 36.9 | 60.8 | 84.7 | 114.3 | 130.5 | 0.095 |
| Natural | 40.1 | 60.4 | 88.2 | 116.1 | 139.6 | 0.141 |
| | | | | **Average** | | |
| Redhaven | 37.5 | 60.5 | 85.0 | 112.4 | 129.9b | 0.187a |
| Redskin | 37.8 | 61.7 | 88.1 | 117.2 | 139.4a | 0.098b |
| | | | | **Total** | | |
| Vase | 36.8 | 63.1 | 89.6a | 119.2 | 142.6a | 0.109b |
| Fan | 37.5 | 59.8 | 83.5b | 110.9 | 129.1b | 0.123ab |
| Natural | 38.8 | 60.4 | 86.7ab | 114.2 | 132.4ab | 0.196a |

*Mean separation by Duncan's new multiple range test, 5 % level.
†Full crop year.
‡Partial crop year.

west sides of the hedgerow were observed. Regardless of system, an average of 36% of the fruit harvested was from the east side tree sections and only 13% from the west sides of the young trees in 1980. Fruit color was not different from west (2.71) and east (2.67) sections. Several reasons may account for differences in yield between east and west sides of the peach hedgerows: 1) an ecological factor — trees may have had an eastern slant due to prevailing westerly winds, and therefore the tree canopy may have been more dense on the eastern side after repeated hedging and had more fruiting shoots; 2) physiological factors — differences in shoot growth and flower bud formation (7); 3) differences in bloom, pollination, and susceptibility to frost (4).

During the 1980 harvest, percent full sun in 'Redskin' was 33% higher in west side sections (45.2% FS) than east sections (34.1% FS) (Table 1). Since fruit buds would have been formed prior to this time, light differences would not account for difference in fruit bud formation. There was no difference between light in east or west tree sides at mid-season, either before or after hedging (Table 2). Light early in the season was not measured in this study, yet may be critical to fruit set and return flower bud formation.

### Tree Efficiency

Trunk cross-sectional area is an index of total tree growth (8). 'Redskin' peach trees had a larger trunk cross-sectional area than 'Redhaven' by the sixth year of growth, but had lower yield efficiency in the same year (Table 5). Trunk cross-section of trees in the vase system was larger than of trees in the fan system. This is probably a result of the more severe dormant pruning fan trees received, while vase trees were allowed a larger canopy development.

Trees of the natural system were a more efficient (yield/cross-section) system than the open-center vase (Table 5). The fan training system was intermediate in efficiency, compared to the vase or natural systems.

## CONCLUSIONS

Training system will affect the light distribution and cropping of peaches grown in hedgerows. This study, with just 2 years of light and harvest data, indicates that the natural tree system may have benefits of increased cropping and efficiency. This system also had the benefit of minimal dormant pruning, which is a high labor cost. However, due to the proliferation of small twiggy growth, which tends to die annually inside the tree, harvest may be more difficult. The vase and fan training systems may have an increased ability to withstand ice breakage from sprinkler frost protection. 'Redhaven' was more productive and efficient than 'Redskin'.

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# Advective and Radiative Frost Control with Irrigation in Peaches[1]

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## INTRODUCTION

In the last decade, peach production in the Midwest has been very erratic due either to freeze damage to the flower buds in the winter or frost damage in the spring. These losses have been so extreme that many growers have pulled orchards and are producing other crops. However, growers who persist in peach production have found eager markets and good returns in the years when they have a crop.

The problem of winter freeze injury due to low temperatures can be minimized through selection of rootstocks and cultivars more tolerant to extreme and fluctuating temperatures, careful choice of sites with excellent air and soil drainage, and maintenance of plant vigor through judicious fertilization and pest control practices. Although beneficial, these practices may not be adequate to save the crop when temperatures approach −20° F (−29° C) in mid-winter.

Spring frost damage to flower buds can best be avoided by planting peaches on elevated sites with good air drainage or in close proximity to large bodies of water (Lake Erie) which modify spring temperatures. In addition to this primary method of frost avoidance, heating of orchards, air mixing by helicopters or wind machines, the use of techniques to delay bloom, or a combination of these techniques have been used to avoid flower bud damage. However, reduced availability and higher costs of fossil fuels (natural gas, propane, or fuel oil) and occasional inconsistent results with air mixing systems have stimulated interest in alternative methods.

Previous Ohio studies (Stang *et al.*, 1977) on the use of overhead sprinkling to delay bloom of peaches indicated that bloom could be delayed. However, fruit set was reduced and the application of water over an extended time on already saturated soils was not desirable on most Ohio soils.

Overhead sprinkler irrigation has been used successfully as a method of frost protection on strawberries for many years and in recent years has been used successfully on tree fruits as well. However, the brittle nature of peach wood raised questions whether this would be a desirable practice with peach.

## THE ORCHARD

In order to gain some experience with this practice and determine if a modification of tree form influenced the ability of the tree to carry the ice load, a planting was established at OARDC in 1978. Red Haven and Redskin on Siberian C rootstock were planted in alternating rows at a spacing of 3 m x 4.5 m (approximately 10 ft x 15 ft). The trees were trained in one of the following three hedgerow systems: 1) natural tree headed at planting and initial scaffold selection made the following year; in subsequent years only broken limbs were removed and tree spread was maintained by mechanical hedging [2 ft (0.6 m) at the top and 5 ft (1.5 m) at the bottom]; 2) fan trees headed at planting and the following years branches growing into the row middle were removed so that a narrow tree form developed with shape maintained as described for the natural system; 3) vase trees were trained to a conventional open center with wide crotch angles achieved. A tree width of 7 ft (2.1 m) was maintained by mechanical summer hedging. A cutter-bar mower was used annually to cut new growth in half in mid-June and regrowth was halved in mid-July when all trees were topped at 8 ft (2.4 m). The treatments were arranged so that 10 trees of each cultivar/training system were in each irrigation block.

In 1980, a year of no frost during bloom, these trees produced their first crop 3 years after planting. The yields were: Red Haven natural, 493 bu/a; vase, 438 bu/a; fan, 454 bu/a; and Redskin natural, 369 bu/a; vase, 326 bu/a; and fan, 329 bu/a. These were exceptional yields for 3-year-old trees and clearly indicate the advantages of intensive planting. Unfortunately, winter freezes eliminated the crops in 1981 and 1982.

## 1983 FROST EVENTS AND IRRIGATION PLANS

In the spring of 1983, the flower buds were viable and approaching the pink stage when temperatures reached lows of about 19° F (−7.2° C) early on April 18 and about 25° F (−3.7° C) early on April 19. Bud critical temperature tolerance was estimated to be 21° to 25° F (−6.1° to −3.9° C). The advective-freeze conditions were due to a large cold-air mass with daytime wind velocities of 7 to 15 miles per hour (3.1 to 8.7 m/sec). This system affected local weather conditions for 3 days and prevented melt-off of ice during the day of April 18. Skies were lightly overcast both nights.

Normally, under these conditions of high winds and temperatures already below the freezing point, irrigation would not be used for frost control because of the

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chance of killing buds by supercooling when sprinkling was started. However, we were interested in determining the effects under these severe conditions and decided to sprinkle half of the experimental orchard block. Irrigation started at 10 p.m. on April 17 when air temperature had already fallen to about 23° F (−5° C). Sprinkling on one section of the orchard was stopped during the morning of April 18 and was resumed at 7:35 p.m. Sprinkling was stopped and all ice melted off by noon on April 19. Water was applied at the recommended rate of about 0.1 inch (0.25 cm) per hour.

On May 8, 9, and 10, frost conditions again occurred. Air temperature dropped rapidly on May 8 and reached a low of 27.7° F (−2.4° C) early on May 9. During the night of May 9-10, air temperature attained a low of 28.4° F (−2.0° C). Both nights were clear, with light winds of about 1 to 2 miles per hour (0.4 to 0.9 m/sec), westerly, typical of radiation frost conditions commonly affecting Ohio in middle to late spring. The trees had reached the late bloom and small-fruit stage with a critical temperature tolerance estimated to be 25° F (−3.9° C).

In the May 8-10 operations, sprinkling was started when the air temperature reached about 32° F (0° C). Sprinkling was started at 2:30 a.m. in the May 10 application, which is a case of interest in this report. Bud temperatures were typically maintained at or above 30.6° F (−1.0° C) throughout the night when sprinkled. Sprinkled buds were at about 2° F (1° C) above air temperature in the May 8-10 operations.

## LOCAL ATMOSPHERIC STABILITY

The dimensionless *gradient Richardson number* (Ri) served as an index of stability in this study. Mean temperature and velocity differences over vertical distances of 3.6 and 4.4 m (11.8 and 14.4 ft), respectively, were used to estimate the values of Ri. Generally, values of Ri less than 0.2 indicate that pre-existing turbulence and its accompanying atmospheric mixing effect will be sustained as in some advective conditions, for example. Values of Ri greater than 0.2 usually indicate that any pre-existing turbulence will tend to be suppressed, as in stratified, stable conditions.

Table 1 is a summary of hourly values of Ri from the three sets of frost conditions encountered in this work. Almost all Ri values were near or less than 0.2 on April 17-19, indicative of the sustained turbulent mixing prevailing in the advective freezing conditions. For May 10, all values of Ri were greater than 0.2 and indicate turbulence suppression and stable conditions. These observations emphasize the importance of air movement in occurrence of frost conditions and in the success of frost protection operations. Air movement and turbulence can help retard establishment of stratification and perhaps forestall the accompanying temperature inversions typical of radiation frost conditions. However, under sufficiently cold advective-freeze conditions, air movement and turbulence mixing, with their acceleration of heat transfer, can be disastrous to fruit crops.

## ICE DAMAGE AND FRUIT YIELD

The extremely heavy ice load (Fig. 1) from irrigation under low temperatures resulted in significant structural damage to the trees (Fig. 2) from the April 17-19 operations. Since the ice coating applied April 17-18 did not melt during the day of April 18, some ice cover also slipped outward on the tree branches during the day, an effect which compounded the bending load on the branches.

Following irrigation, limb breakage was assessed by

**TABLE 1.—Gradient Richardson Numbers (Ri) for April and May 1983 Frost Protection Studies.**

| Experiment Date | | | | | |
|---|---|---|---|---|---|
| April 17-18 | | April 18-19 | | May 10 | |
| Date and Time (EST) | Ri | Date and Time (EST) | Ri | Date and Time (EDST) | Ri |
| Apr 17 p.m. | | Apr 18 p.m. | | May 10 a.m. | |
| 10.00 | 0.057 | 7:20 | 0.224 | 1:30 | 0.25 |
| 11:00 | −2.64 | 8:20 | 0.053 | 2:30 | 4.80 |
| 12:00 | −0.005 | 9:20 | 0.022 | 3:30 | 49.51 |
| Apr 18 a.m. | | 10:20 | −0.0273 | 4:30 | 3.86 |
| 1:00 | 0.008 | 11:20 | 0.0233 | 5:30 | 0.87 |
| 2:00 | 0.003 | Apr 19 a.m. | | 6:30 | 116.2 |
| 3:00 | 0.005 | 12:20 | 0.013 | 7:30 | 0.80 |
| 4:00 | 0.006 | 1:20 | 0.015 | 8:30 | 1.27 |
| | | 2:20 | −0.023 | | |
| | | 3:20 | −0.010 | | |
| | | 4:20 | −0.008 | | |
| | | 5:20 | −0.033 | | |
| | | 6:20 | −0.025 | | |
| | | 7:20 | −0.027 | | |

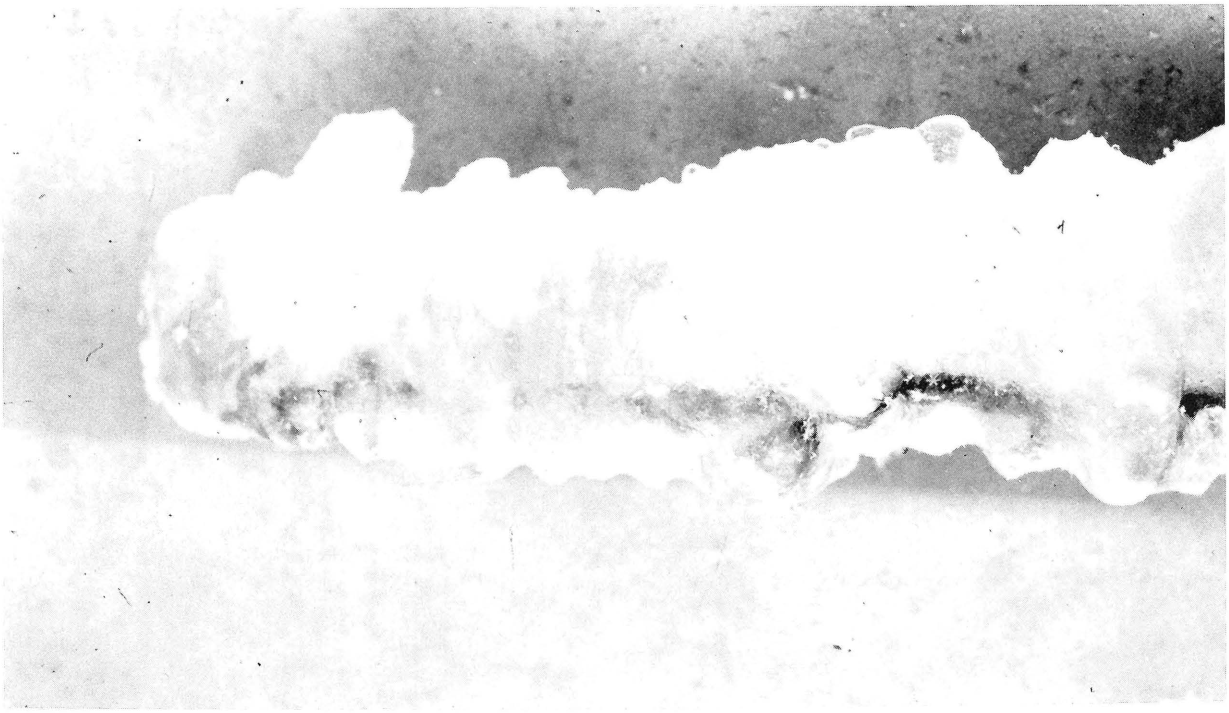

FIG. 1.—Excessive ice build-up on a 1-year-old peach twig due to the long duration of extremely low temperatures during irrigation for frost protection.

FIG. 2.—Limb and twig breakage in peach trees due to the heavy build-up of ice during irrigation for frost protection under severe conditions.

counting and measuring broken limbs (Table 2). Generally, few large scaffold limbs were lost. Secondary limb breakage increased as the ice load increased on the second day of continuous irrigation. Red Haven demonstrated slightly more breakage after 1 day of irrigation but there was no difference following the increased ice load of the second day.

It appears from the data that the fan system, particularly with Redskin, had less breakage than the other systems. However, by random chance the fan in each of these blocks was the outside west row and had less ice build-up than the interior rows (Fig. 3). When the fan system received heavy ice build-up, as evidenced by Red Haven trees, breakage was severe. Thus, the ice load under these conditions was beyond the structural capacity of the trees and training system had little influence. The heavy ice loads had little effect on average tree leaning, although two trees were completely uprooted.

As ice was building up, periodic checks for limb breakage showed that the thicker natural system trees began breaking earlier. The many small crossing twigs froze together, ice accumulated rapidly, and breakage occurred. In the fan and vase systems which were well pruned and had few crossing limbs, the ice build-up occurred more slowly and breakage occurred later. Thus, if overhead sprinklers are used for frost control under more normal, less severe conditions, well-pruned open trees will be better able to survive than thick trees. The tremendous ice load carried on these trees before breakage occurred alleviated most of the authors' concerns about the brittle nature of peach wood and the potential for the use of irrigation for frost control.

The May 8-10 experiments took place under conditions more nearly suited to frost protection operations. A large ice accumulation did not occur either night and melt-off occurred as expected during the mornings of May 9 and 10. Therefore, there was little or no further ice damage to the trees.

Typical dry-bulb, dew point, and bud (sprinkled and unsprinkled) temperatures from the April 17-18, April 18-19, and May 9-10 experiments are plotted in Figures 4, 5, and 6, respectively. It is important to note that in all cases humidity levels were sufficiently high to limit the rate and amount of fall in dry-bulb air temperature. In particular, on April 17-18 and May 9-10, dewpoint temperature tracked the air temperature closely, which indicated high relative humidities. As humidity increases, one can expect the cooling effect of radiation to

**TABLE 2.—Influence of Irrigation for Frost Control on Cropping and Effect of Ice Buildup on Limb Breakage of 6-Year-Old Peach Trees on Siberian C Rootstock.**

| | Limb Breakage | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Scaffolds | | Secondary | | | | | |
| | No./ Tree | No. Broken | Av. Size Broken (cm) | No. Broken | Av. Size Broken (cm) | Lean Degree from 90° | Fruit Density Fruit/cm | Yield kg/t | Yield bu/a |
| | | | | Unirrigated Control | | | | | |
| **Red Haven** | | | | | | | | | |
| Natural | 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 8.5 | 16.7 | 37.2 | 476 |
| Fan | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.5 | 8.9 | 26.2 | 335 |
| Vase | 3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.1 | 31.6 | 404 |
| **Redskin** | | | | | | | | | |
| Natural | 3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 7.0 | 4.5 | 24.7 | 316 |
| Fan | 3.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.4 | 11.9 | 152 |
| Vase | 3.8 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 0.2 | 7.6 | 97 |
| | | | | Irrigated April 18 Only | | | | | |
| **Red Haven** | | | | | | | | | |
| Natural | 4.5 | 0.3 | 5.73 | 1.2 | 2.86 | 3.0 | 6.2 | 26.3 | 336 |
| Fan | 4.0 | 0.7 | 5.20 | 3.1 | 1.64 | 4.5 | 4.8 | 15.1 | 193 |
| Vase | 3.8 | 0.0 | 0.0 | 2.8 | 1.63 | 0.0 | 4.3 | 15.6 | 199 |
| **Redskin** | | | | | | | | | |
| Natural | 4.1 | 1.1 | 4.85 | 2.8 | 2.31 | 13.3 | 1.7 | 11.7 | 150 |
| Fan | 4.1 | 0.0 | 0.0 | 0.1 | 0.75 | 2.5 | 2.9 | 14.2 | 179 |
| Vase | 3.8 | 0.4 | 5.69 | 3.0 | 2.33 | 6.9 | 0.2 | 6.1 | 78 |
| | | | | Irrigated April 18 and 19 | | | | | |
| **Red Haven** | | | | | | | | | |
| Natural | 4.7 | 0.0 | 0.0 | 1.3 | 2.91 | 6.7 | 0.1 | 30.3 | 388 |
| Fan | 3.4 | 2.2 | 7.38 | 4.2 | 2.45 | 1.1 | 2.4 | 13.0 | 166 |
| Vase | 4.1 | 0.5 | 5.44 | 3.4 | 1.88 | 1.1 | 3.4 | 10.9 | 139 |
| **Redskin** | | | | | | | | | |
| Natural | 3.9 | 0.6 | 7.75 | 5.2 | 3.13 | 9.5 | 0.8 | 12.4 | 158 |
| Fan | 3.1 | 0.0 | 0.0 | 0.1 | 1.24 | 0.0 | 0.1 | 1.1 | 14 |
| Vase | 4.1 | 0.9 | 7.53 | 3.4 | 2.48 | 12.5 | 0.4 | 3.0 | 38 |

FIG. 3.—Outside west row showing very little ice build-up due to inadequate sprinkler coverage.

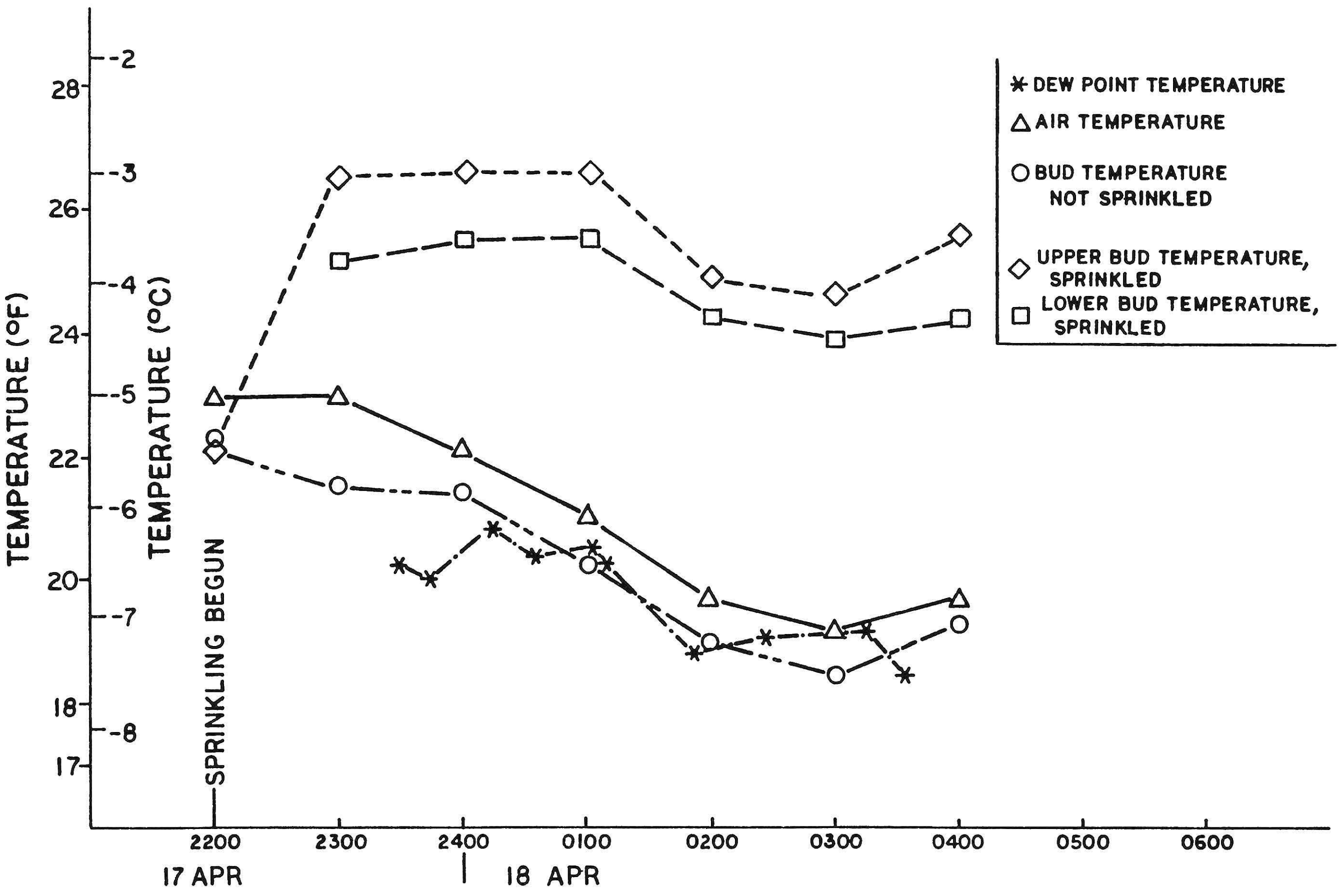


FIG. 4.—Plot of air and dew point temperatures outside the peach orchard during the night of April 17-18, 1983. Temperatures of sprinkled and unsprinkled buds are also shown.

be lessened, and latent heat is also released as frost formation begins, effects which can retard temperature fall.

The light cloud cover prevailing during the April advective freezes is also likely to have limited the severity of the frost event to some extent.

Figures 4, 5, and 6 show that irrigation produced definite warming of the buds, but despite this beneficial effect the April ice-loading damage ultimately reduced yield. Yield data further show that fruit density (fruit/cm limb circumference) was generally reduced when water was applied under the severe conditions of the April experiments. However, it is interesting to note that the crop was not entirely eliminated by starting the April irrigation on buds which had reached 24° F (—4.4° C). In contrast to these findings, it remains that while killing of some buds occurred, the unsprinkled trees still produced significant yields of fruit. Apparently ice damage to the trees due to the April operations was a major factor in more than offsetting any saving in buds which may have occurred. Thus, it appears that a decision not to irrigate would have been correct in the case of the April advective freeze conditions.

The recommendation appears sound not to operate sprinkler systems for frost control under windy conditions or when the temperature drops well below the threshold of 32° F (0° C) before the system can be started. Until there has been further research under Ohio conditions, it may be unsafe to irrigate despite the fact that supercooling did not occur.

It further appears that significant numbers of buds on unsprinkled trees were able to survive owing to favorable combinations of humidity, cloud cover, and air movement effects. It is likely that humidity level was a key factor. Ambient and dew point temperatures in Figs. 4 and 5 correspond to relative humidities ranging from about 75% to essentially 100% as the nights progressed during the April 17-19 events. Similarly high humidities were also noted during the less severe frost conditions occurring on May 8-10 as reflected in Fig. 6.

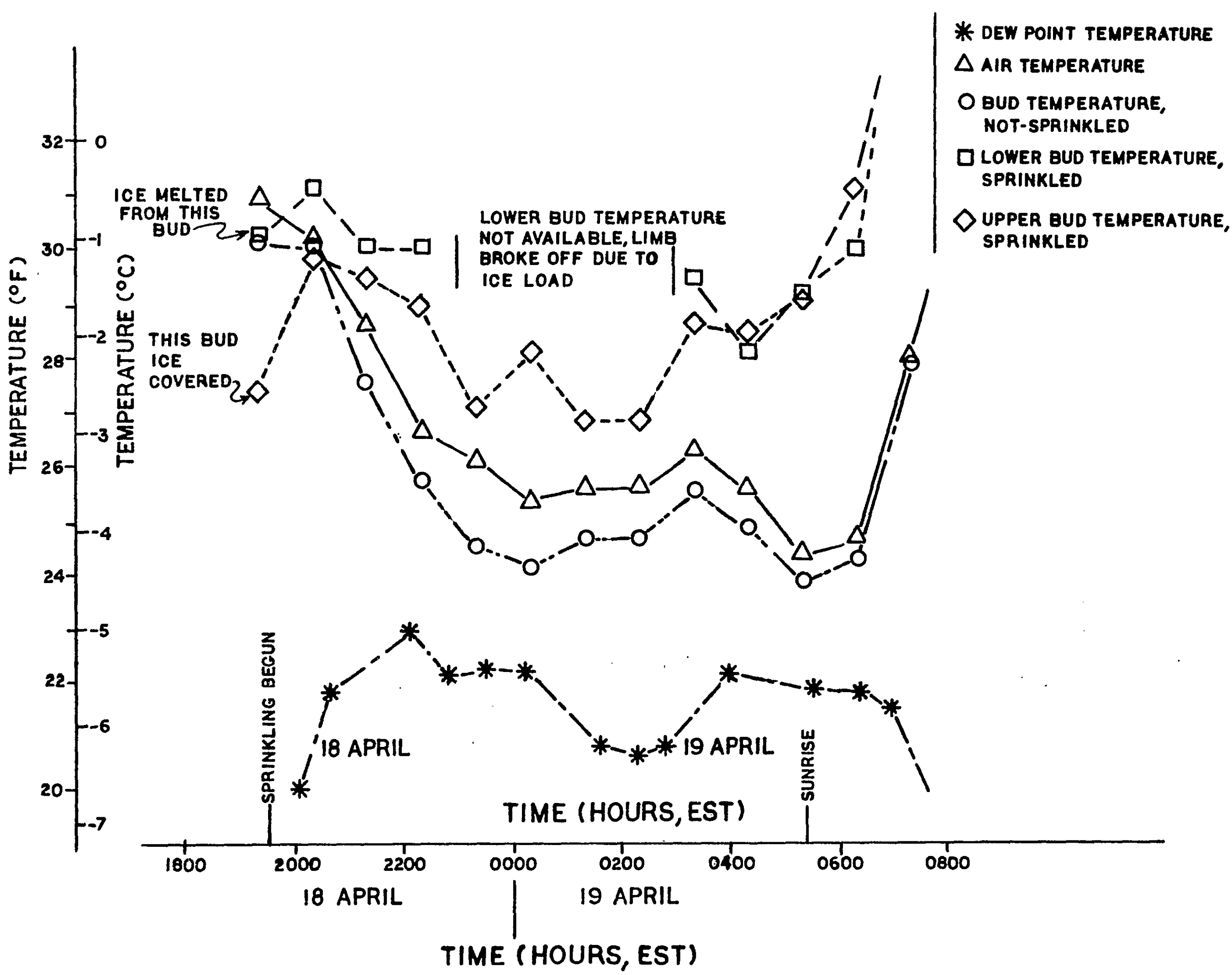


FIG. 5.—Plot of air and dew point temperatures outside the peach orchard during the night of April 18-19, 1983. Temperatures of sprinkled and unsprinked buds are also shown.

The significant humidity levels encountered served as suppliers of latent heat, tended to limit radiation heat loss from the soil, and apparently suppressed super cooling.

## FROST PROTECTION

Frost predictions are of critical interest in crop protection operations. Advance estimates of the minimum temperature can serve as a warning for setting alarms or to alert the user to the need for special preparations. Thus, it was of concern whether some *local* frost prediction estimates could be developed for the conditions studied.

Efforts to predict minimum temperatures are believed to date back to at least 1885. Bagdonas *et al.* (1978) discuss a number of formulas and schemes developed over the years. Cloud cover, wind velocity, and humidity are important factors in prediction. However, humidity is one of the key parameters and has received the most attention. Some general minimum-temperature theories have been developed, but the use of their complicated formulas is probably not justified until more field data are available. It is also important to note that frost prediction schemes are likely to be at least in part site-dependent. Therefore, it seems desirable for the user to develop data for each orchard site owing to local factors such as topography, soil cover, air drainage, or proximity to bodies of water.

It has been found that the difference, $T_m - T_d$, between night minimum temperature, $T_m$, and evening dew point temperature, $T_d$, for the preceding day provide a useful prediction relationship when plotted against the same evening percent relative humidity, $P_h$. Figure 7 shows such a plot for data from a weather station in California, as given by Sutton (3). Data from the present studies appear on the same plot.

While plots for a given orchard site can be used as prediction aids, a formula statistically fitted to the data may sometimes be more convenient. A computer or calculator can then be used to facilitate the prediction process. Sutton (3) suggests that a second-degree polynomial can be used to represent data as shown in Fig. 7. However, Sutton also mentions that exponential or other mathematical forms may fit the data equally well. In this study, a second-order polynomial was compared with an exponential equation of the form:

$$T_m - T_d + A = B \exp(CP_h) \qquad (1)$$

where A, B, and C are constants to be determined. We found that equation (1) represented the California data

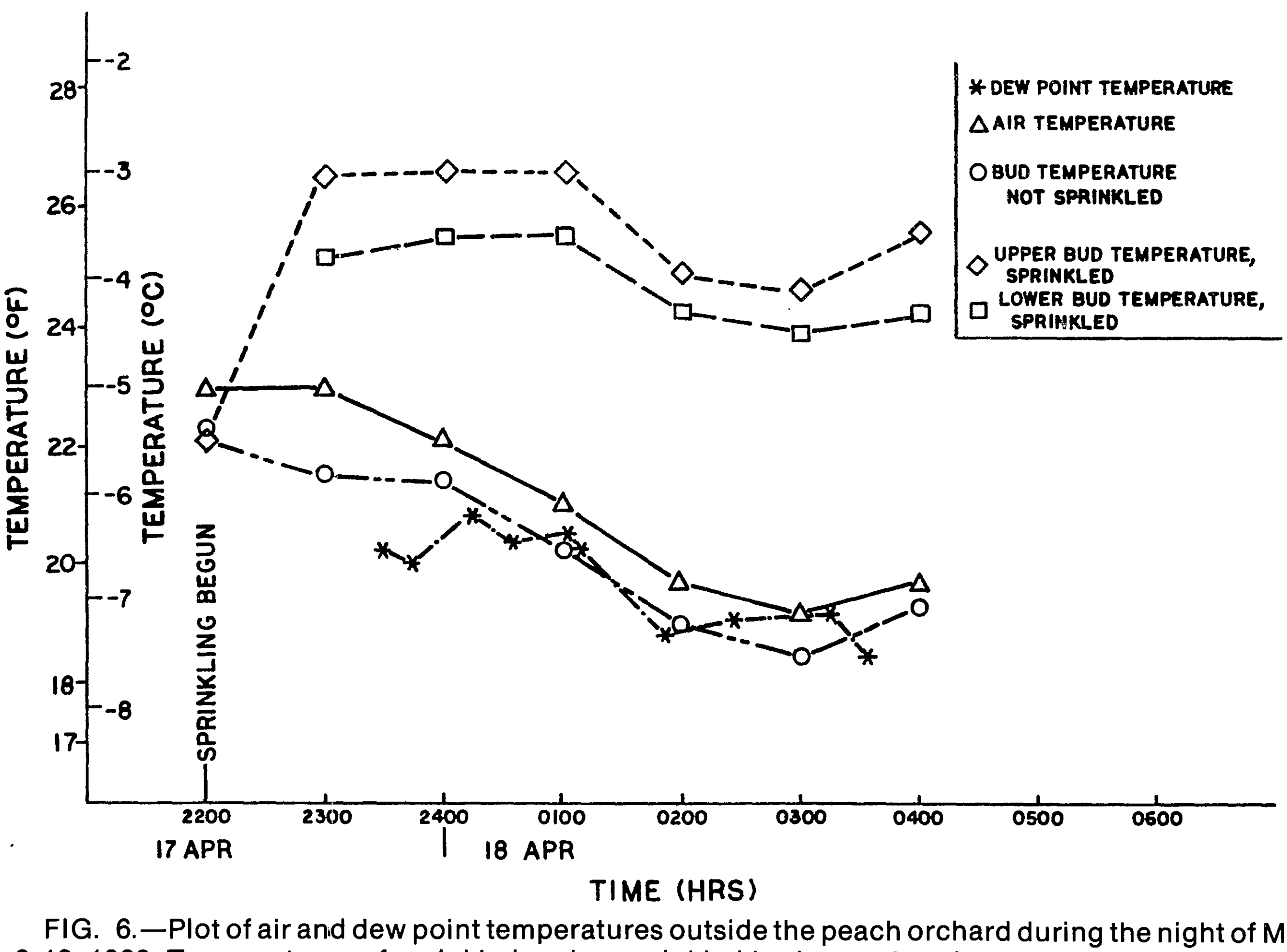


FIG. 6.—Plot of air and dew point temperatures outside the peach orchard during the night of May 9-10, 1983. Temperatures of sprinkled and unsprinkled buds are also shown.

more satisfactorily than a second-degree polynomial. Also, the method of equation (1) was more easily implemented on an inexpensive calculator with statistical capability. Therefore, equation (1) was applied to our data.

Figure 7 shows that our data merge with the California data reasonably well. However, the two sets of data begin to exhibit excessive deviation for $P_h$ values less than about 35%. Hence, equation (1) was fitted to the pooled California and 1983 Ohio data. The resulting equation, when solved for the minimum air temperature, $T_m$, was:

$$T_m = 51.8 \exp(-0.0293P_h) - 10 + T_d. \quad (2)$$

The value A = 10 is somewhat arbitrary and was chosen so that the quantity $T_m - T_d + A$ would not become negative for the available data.

Table 3 is a comparison of predicted and observed minimum temperatures for the 1983 experiments. Agreement is generally good, as might be expected. However, we would expect improvement in the predictions with the availability of additional data which would also offer the opportunity for classifying the data into groups for advective, radiative, clear, or cloudy conditions.

Relatively inexpensive instruments and a psychrometric chart can be used to develop the required input data on humidity. In this study, a psychrometric program was available for a microcomputer, and additional synoptic weather data were available from the OARDC Auto-Weather Network. It is advisable to include confidence limits or tolerances for the data, as stated in Table 3 and shown in Fig. 7. Confidence limits can be easily determined with the calculator.

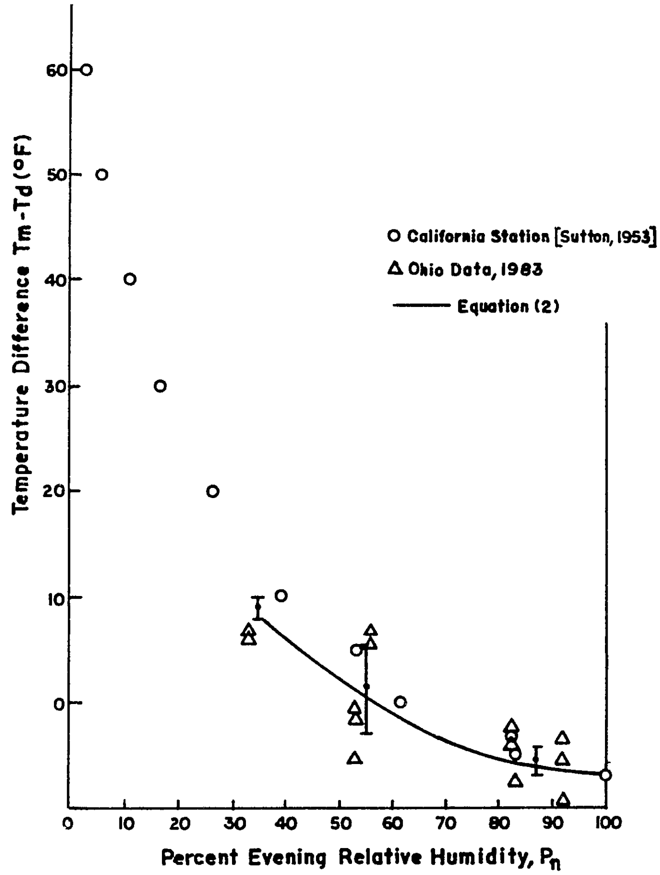


FIG. 7.—Relation of difference ($T_m - T_d$) between minimum nighttime temperature ($T_m$) and evening dew point ($T_d$) to percent evening relative humidity ($P_h$).

TABLE 3.—Predicted and Measured Minimum Nighttime Temperatures.

| Date | Evening Time, t | Evening Humidity Data $P_h$ (t) | Evening Humidity Data $T_d$ (t) (° F) | Minimum Temperature* Observed $T_m$ (° F) | Minimum Temperature* Predicted $T_m'$ (° F) | Prediction Error $T_m - T_m'$ (° F) |
|---|---|---|---|---|---|---|
| Apr 17 | 7:00 p.m. (EST) | 91.6 | 28.5 | 25.0 | | |
| | | | | 19.2 | | |
| | | | | 23.1 | | |
| | | | Mean | 22.4 ± 3.0 | 22.0 ± 2.1 | +0.4 |
| Apr 18 | 7:00 p.m. (EST) | 82.5 | 27.0 | 23.0 | | |
| | | | | 24.3 | | |
| | | | | 23.7 | | |
| | | | Mean | 23.7 ± 0.7 | 21.6 ± 2.1 | +2.1 |
| Apr 19 | 7:00 p.m. (EST) | 55.9 | 21.3 | 28.0 | | |
| | | | | 27.0 | | |
| | | | Mean | 27.5 ± 0.7 | 21.4 ± 4.5 | +6.1 |
| May 8 | 8:00 p.m. (EDT) | 83.0 | 34.5 | 29.0 | | |
| | | | | 27.0 | | |
| | | | Mean | 28.0 ± 1.4 | 29.0 ± 2.1 | −1.0 |
| May 9 | 8:00 p.m. (EDT) | 53.2 | 28.7 | 28.0 | | |
| | | | | 23.4 | | |
| | | | | 27.2 | | |
| | | | Mean | 26.2 ± 2.5 | 29.6 ± 4.5 | −3.4 |
| May 10 | 8:00 p.m. (EDT) | 33.2 | 26.2 | 33.0 | | |
| | | | | 32.8 | | |
| | | | Mean | 32.9 ± 0.1 | 35.8 ± 1.9 | −2.9 |

*Minimum temperatures listed occurred during the early morning of the day following the specified date, usually just before or at about sunrise.

## SUMMARY

The results of this study particularly underscore the importance of humidity as a factor in management decisions on frost protection.

In addition to the apparent suppression of supercooling, a more critical benefit appears to be limiting the rate and degree of temperature drop. However, it is important to remember that cloud cover and wind velocity are also important factors determining whether temperature fall will be sustained and whether radiative or advective frost conditions will prevail. In particular, wind velocity and turbulence are indicative of the degree of atmospheric stability and strength of inversion conditions.

The results of this study support the advisability of not irrigating under high wind or advective frost conditions. The risk of tree damage is likely to offset any savings in bud losses. Humidity forecasts given in weather advisories or humidity sensors will be helpful in making such determinations.

A localized frost prediction scheme was suggested for possible grower use. The method encourages the development of a minimum-temperature:evening humidity data "history" for an orchard site. The data should maintain value for use with improved forecast algorithms or formulas which may become available in the future. The suggested method can be fairly easily adapted to a microcomputer or relatively inexpensive constant-memory calculator with statistical capability. Predictor methods have the potential for improved management of frost protection operations, particularly when considerable lead time is needed to activate a frost-protection system.

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# Effects of Herbicides on Newly Planted 'Brandywine' Purple Raspberry

**J. A. ERF and R. C. FUNT[1]**

## INTRODUCTION

Controlling weeds in brambles (raspberries and blackberries) is necessary for their successful growth. Weeds compete with brambles for soil moisture, soil nutrients, carbon dioxide, and light. Weed roots may also produce noxious substances which inhibit crop growth.

A recent survey of Ohio's bramble industry indicates weed control as a major concern (2). Newly planted bramble canes are at a particular disadvantage when competing with spring-germinating weeds in that transplants are dependent on the production of new canes for survival. Lawson and Wiseman (6, 7) have shown the importance of preventing weed competition during this critical period of cane emergence.

Weed control delayed 12 and 16 weeks in newly planted raspberries resulted in yield reductions of 50 and 74%, respectively. Weed growth left undisturbed throughout the growing season killed many plants the first year and reduced fruit yield 90% the second year. Weed competition can severely affect total cane growth of raspberries in the season of planting. Also, numbers of canes produced by the end of the second growing season continue to show the effects of competition from weeds during the previous year (7).

In Ohio, cultivation has been the primary method of weed control in newly planted bramble plantations. Mechanical cultivation is expensive, time consuming, and may cause physical crop injury. The use of herbicides can help solve this problem and benefit fruit growers. Current recommended herbicides for newly planted brambles have resulted in variable weed control. Phytotoxicity may also be a problem. There is a need for alternatives to the currently labeled herbicides.

The objective of this study was to evaluate the effect of several herbicides, alone and in combination, on the growth of newly planted 'Brandywine' purple raspberries. Specifically, the goal of this research was to find a herbicide treatment which was non-phytotoxic and provided satisfactory weed control.

## MATERIALS AND METHODS

A bramble planting was established at the OSU Horticulture Research and Teaching Farm in Columbus. In late April 1980, uniform purple raspberry plants (cv. 'Brandywine') were hand planted on a silt-loam soil with an organic matter content of 3.0 to 3.3% and a pH of 6.3. This ground had been fallow for 1 year following the removal of a 20-year-old apple orchard.

A completely randomized design of 14 herbicide treatments with four replications was used. There were six transplants per replication. The treatments and rates were as follows:

- Hand-weeded check
- Unweeded check
- Oryzalin at 2.2 kg ai/ha (Surflan 5G)
- Oryzalin at 4.5 kg ai/ha (Surflan 5G)
- Oryzalin at 6.7 kg ai/ha (Surflan 5G)
- Napropamide at 2.2 kg ai/ha (Devrinol 10G)
- Napropamide at 4.5 kg ai/ha (Devrinol 10G)
- Napropamide at 6.7 kg ai/ha (Devrinol 10G)
- Simazine at 1.8 kg ai/ha (Princep 4G)
- Simazine at 1.8 + Oryzalin at 2.2 kg ai/ha (Princep 4G + Surflan 5G)
- Simazine at 1.8 + Oryzalin at 4.5 kg ai/ha (Princep 4G + Surflan 5G)
- Simazine at 1.8 + Napropamide at 2.2 kg ai/ha (Princep 4G + Surflan 5G)
- Simazine at 1.8 + Napropamide at 4.5 kg ai/ha (Princep 4G + Devrinol 10G)
- Oryzalin at 2.2 + Napropamide at 2.2 kg ai/ha (Surflan 5G + Devrinol 10G)

After planting, granular herbicides were diluted with sand and applied in 100 cm wide strips with a hand shaker.

Due to a lack of rainfall, irrigation was necessary for plant survival and herbicide activation. Plants were individually watered 4 days after planting and plots were irrigated with a modified 500-gallon orchard sprayer 10 days after herbicide application. The plants received sufficient natural rainfall the remainder of the season. In early summer, a complete fertilizer of 12-12-12 was applied to the planting at 22.4 kg/ha.

During the growing season, observations were recorded for weed control and phytotoxicity symptoms. Ten weeks after planting, weed control for each plot was rated on a scale from 1 to 5. Plots were judged with no knowledge of the treatment being observed. Plants were harvested in late September at which time cane length, cane number, and cane dry weights were determined.

## RESULTS AND DISCUSSION

As shown in Table 1, average cane height was significantly less in unweeded and simazine 1.8 kg/ha only treated plots compared to all other treatments. Hand-weeded, oryzalin 4.5 kg/ha, oryzalin 6.7 kg/ha, simazine 1.8 kg/ha + oryzalin 2.2 kg/ha, simazine 1.8 kg/ha + oryzalin 4.5 kg/ha, and simazine 1.8 kg/ha + napropamide 4.5 kg/ha treated plants had greater total cane length than unweeded and simazine 1.8 kg/ha treated plants. Total dry weight was greater in hand-weeded, oryzalin 4.5 kg/ha, oryzalin 6.7 kg/ha, and simazine 1.8 kg/ha + oryzalin 2.2 kg/ha treated plants than unweed-

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**TABLE 1.—Effects of Herbicide Treatments on Growth of Newly Planted 'Brandywine' Purple Raspberry.***

| Treatments (kg ai/ha)† | Percent Transplant Survival‡ | Av. Canes per Transplant | Av. Cane Height (cm) | Total Cane Length (cm) | Av. Rep. Dry Wt. (g) |
|---|---|---|---|---|---|
| Hand-weeded | 100a | 4.7a | 138a | 4326ab | 1151ab |
| Unweeded | 95a | 2.9a | 76b | 1271d | 207e |
| Oryzalin 2.2 | 91a | 4.0a | 147a | 3243abc | 813abc |
| Oryzalin 4.5 | 95a | 4.3a | 155a | 4189ab | 1197a |
| Oryzalin 6.7 | 91a | 4.3a | 140a | 4965a | 1188ab |
| Napropomide 2.2 | 100a | 4.2a | 118a | 3287abc | 681bcd |
| Napropamide 4.5 | 95a | 3.8a | 129a | 3245abc | 758abcd |
| Napropamide 6.7 | 100a | 3.4a | 144a | 3159abc | 816abcd |
| Simazine 1.8 | 100a | 3.4a | 84b | 1812cd | 362de |
| Simazine 1.8 + Oryzalin 2.2 | 100a | 4.1a | 145a | 4771a | 1168ab |
| Simazine 1.8 + Oryzalin 4.5 | 95a | 3.9a | 145a | 3966ab | 1016abc |
| Simazine 1.8 + Napropamide 2.2 | 95a | 3.5a | 129a | 2698bcd | 553cde |
| Simazine 1.8 + Napropamide 4.5 | 95a | 3.9a | 151a | 3736ab | 926abc |
| Oryzalin 2.2 + Napropamide 2.2 | 100a | 3.9a | 142a | 3510abc | 933abc |

*Means followed by same letter are not significantly different at the 5% level, Duncan's new multiple range test.
†Active ingredient per hectare.
‡Percent transplant survival 20 weeks after planting, six transplants/six new plants = 100%.

ed, simazine 1.8 kg/ha, and simazine 1.8 kg/ha + napropamide 2.2 kg/ha treated plants. There were no significant differences between treatments with respect to cane survival and average number of canes per plant.

Visual observation throughout the growing season indicated oryzalin 4.5 kg/ha, oryzalin 6.7 kg/ha, simazine 1.8 kg/ha + oryzalin 2.2 kg/ha, and simazine 1.8 kg/ha + oryzalin 4.5 kg/ha treated plots had the highest weed control ratings (Table 2). The herbicide treatments having the lowest weed control ratings were napropamide 2.2 kg/ha, simazine 1.8 kg/ha, and simazine 1.8 kg/ha + napropamide 2.2 kg/ha treatments. Yellow foxtail, barnyard grass, fall panicum, and large crabgrass were responsible for the majority of weed cover. Other problem broadleaved weeds consisted of red-root pigweed, lambsquarter, and purslane.

**TABLE 2.—Evaluation of Herbicides for Weed Control in 'Brandywine' Purple Raspberries, 10 Weeks After Application.**

| Treatments (kg ai/ha)* | Weed Control† |
|---|---|
| Hand-weeded | 5.0a‡ |
| Unweeded | 1.0i |
| Oryzalin 2.2 | 2.3cde |
| Oryzalin 4.5 | 2.7bc |
| Oryzalin 6.7 | 3.0b |
| Napropamide 2.2 | 1.5ghi |
| Napropamide 4.5 | 2.1def |
| Napropamide 6.7 | 2.1def |
| Simazine 1.8 | 1.2ghi |
| Simazine 1.8 + Oryzalin 2.2 | 2.6bcd |
| Simazine 1.8 + Oryzalin 4.5 | 2.7bc |
| Simazine 1.8 + Napropamide 2.2 | 1.6fgh |
| Simazine 1.8 + Napropamide 4.5 | 1.7fg |
| Oryzalin 2.2 + Napropamide 2.2 | 2.3cde |

*Active ingredient per hectare.
†Means separation by protected LSD, 5% level.
‡1 equals no weed control, 5 equals total weed control.

Phytotoxicity symptoms occurred primarily in plants treated with simazine alone or in plants treated with simazine in combination with oryzalin or napropamide. Simazine symptoms were characterized by interveinal chlorosis appearing on the older, lower leaves. These symptoms are similar to those reported by Lang (4) for fruit tree seedlings and Curtis (3) for grape cuttings. Sensitivity of 'Brandywine' to this herbicide has been reported in New York (8). Plants treated with oryzalin or napropamide alone showed no apparent phytotoxicity symptoms.

Napropamide-treated plots had low weed control ratings. Poor weed control by napropamide may have been due to photodegradation prior to activation by water. Because irrigation equipment was unavailable, it was 10 days before the herbicide-treated plots received any water. At that time an orchard sprayer was modified and 1.2 cm of water applied. Lang (4) has reported unsatisfactory results with napropamide under conditions where there is excessive delay between herbicide application and soil activation by rainfall or irrigation. Under conditions of high sunlight intensity, 50% of napropamide activity can be lost to photodecomposition after 4 days on the soil surface (9). A delay in herbicide activation in the soil may have allowed germinating weed seedlings to reach a stage of development unaffected by all herbicide treatments. Weed seedlings may have become established early, while later germinating weed seed could still be controlled.

The low rate of simazine used in this study may have been responsible for the lack of weed control in simazine 1.8 kg/ha treated plots. These results agree with other observations of poor weed control on newly planted brambles with low rates of simazine (1, 5). Under normal conditions, loss of simazine from soil by photodecomposition and/or volatilization is considered insignificant (9).

Herbicidal activity of oryzalin may have been greater than napropamide due to oryzalin's greater degree of stability on the soil surface. Oryzalin can be used as a preplant surface application up to 3 weeks before planting without loss of activity (10). Therefore, when the herbicide treatments were activated with water, 10 days after application, most of the oryzalin may not have been degraded.

Some oryzalin-treated plots appeared to have cane growth comparable to hand-weeded plots. 'Brandywine' sucker plants treated with 4.5 and 6.7 kg ai/ha rates of oryzalin alone or in combination with simazine at 1.8 kg ai/ha consistently had greater growth than plants in unweeded plots. Plants growing in napropamide and simazine-treated plots had less growth than plants in oryzalin-treated plots. These treatments were not rated as effective as oryzalin for controlling weeds. Napropamide may not have demonstrated its full potential for weed control due to its late activation by water. Simazine's ineffectiveness for weed control may have been due to the low rates used. When compared to the other herbicides used in this study, oryzalin appears to have the greatest potential for use on newly planted 'Brandywine' transplants.

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# A Summary of Experiments for Control of Sap Beetles which Attack Fruit Crops

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## INTRODUCTION

Sap beetles (Coleoptera:Nitidulidae) cause severe damage to the fruit of strawberry, raspberry, and at times to other fruits, nuts, and vegetables. Even though we have many genera and species of these small beetles in the North Central states, only three species are generally problematic. These are the strawberry sap beetle, *Stelidota geminata* (Say); the picnic beetle, *Glischrochilus quadrisignatus* (Say); and the driedfruit beetle, *Carpophilus hemipterus* (L.).

Previous research on strawberry sap beetle control indicated that application of chemical sprays on strawberry foliage and fruit at rates up to twice the recommended rate did not produce control (2). Conventional chemical control of sap beetles in the field by spraying is difficult due to the protection the beetles receive by being inside or under the fruit being attacked. Malathion has been used successfully for control of the sap beetles in commercial plantations for a number of years. However, in 1976 Kehat *et al.* reported that stronger concentrations of malathion were necessary to achieve even moderate control (3). Apparently, with malathion used continuously for more than 10 years, the sap beetles had developed a degree of resistance.

Over the past 7 years, we have conducted studies with registered and experimental insecticides, looking for better materials to control this group of pests. Three tests were run in the following screening studies: one against each of the genera mentioned above. The experiments were conducted by three former graduate students at different times using different methods.

## METHODS AND MATERIALS

### Experiment I

**Strawberry Sap Beetle:** Strawberry sap beetle adults were laboratory-reared and maintained on autoclaved prunes at 23 ± 2° C and 70% RH under a 16-hr photoperiod. Stock solutions (0.01%) of each insecticide tested were prepared from technical grade materials and diluted with technical grade acetone. Two replicates of 20 beetles each (mixed sex and age) were anesthetized by placing them in a 9.0-cm (3.6 inch) plastic petri dish and placing the dish on a cold surface (ca. 1.0° C). Topical applications (1 microliter/beetle) were applied to the venter of the abdomen with a 0.25-cc glass syringe using a microapplicator.

After treatment, beetles were placed in inverted 9.0-cm plastic petri dishes lined with filter paper discs. A 10% honey solution was added to the filter paper via a plastic squeeze bottle. The honey solution provided a food source as well as water. Controls consisted of two replicates which were treated with the solvent and two untreated replicates. All beetles were placed in an insect-rearing room maintained under the above conditions. Mortality was assessed 24 hr after treatment.

### Experiment II

**Driedfruit Beetle:** Bioassays were conducted by dipping figs (*Ficus carica* 'Calimyrna'), which had been reconstituted with water, in an insecticide suspension. Dipped figs were allowed to air dry for 30 min and then a single fig was placed in a 0.5 pt (473 ml) canning jar. Twenty laboratory-reared driedfruit beetles (mixed age and sex) were added to each jar. The opening of the jar was covered with organdy cloth held in place with the canning ring. The control consisted of figs dipped in distilled water. Each treatment was replicated four times. Containers were held at ca. 23° C and 50-70% RH under a 16-hr photoperiod. Mortality was assessed 24 and 48 hr after treatment.

### Experiment III

**Picnic Beetle:** Seven insecticides were evaluated for the control of the picnic beetle on 'Latham' red raspberries at Wooster. Raspberry rows were 18 inches (46 cm) wide with 6 ft (1.33 m) between the centers of adjacent rows. Plots were 9 ft (2.3 m) long with four replications per treatment in randomized blocks. Treatments were applied on July 12 with a hand operated $CO_2$ sprayer, operating at 45 psi, which was equipped with a TeeJet D3 disc and No. 13 core. Sprays were applied to bushes at the rate of 79 gal/acre (739 l/ha). At each time interval (0, 24, 48, and 72 hr) after application, five ripe berries were harvested from a single replicate and placed in a 150 x 25 mm tissue culture dish. Ten picnic beetles of unknown age and sex were released in a dish and allowed to feed in the confines of the dish for 24 hr before mortality was recorded.

## RESULTS AND DISCUSSION

The screening experiments covered in the preceding section were conducted at different times using different techniques — topical application, dipping host fruit, and spraying host fruit. Although results of the three experiments cannot be directly compared, several insecticides show promise. For example, Guthion gave good control of the strawberry sap beetle and the driedfruit beetle but did not control picnic beetles. However, each

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experiment was conducted with a different species of sap beetle and species often vary in susceptibility to a given compound. In Test I at the 0.01% concentration, Guthion, Mesurol, and Dibrom caused significantly more mortality to the strawberry sap beetle than the other compounds (Table 1).

Mesurol was outstanding in the control of all three species. It appeared to be the No. 1 candidate for the future. However, due to 1984 EPA regulations governing use of Mesurol on grapes for bird control, the interval between last application and harvest was changed from 1 day to 7 days. In 1983 it could be applied to any grapes in Ohio (Section 18), whereas in 1984 it can be used only for wine grapes. At this time Mesurol is not labeled on strawberries or raspberries for any pests.

In the second experiment (Table 2), all of the treatments except Sevin provided total control of the driedfruit beetle at 24 and 48 hr. Sevin had also performed poorly in Experiment I, yielding only 8% mortality at the highest concentration.

An experimental compound, SN-72129 (NOR-AM), which had functioned particularly well against the Colorado potato beetle, *Leptinotarsa decemlineata* (Say), performed quite well in Experiment III against the picnic beetle at every reading (Table 3). However, in another test, Soderstrom & Brandl (4) reported that it gave poor control against the driedfruit beetle. Vaponite (dichlorvos) has been recommended for the control of the driedfruit beetle in California; however, Coviello noted it had produced mixed results on figs in 1983. At high populations, treatments did not seem to significantly reduce damage (1). In our test against picnic beetles, Vaponite was not very effective.

## CONCLUSIONS

In summary, the compounds which are effective and available in our insecticide arsenal are few. Malathion at 2 to 4 lb ai/acre (2.24 to 4.48 kg ai/ha) has been the standard material of choice. It can be used up to 1 day before harvest on raspberries, but the waiting interval on strawberries is 3 days. However, the EC formulation is phytotoxic to raspberries and thus the option would be the WP formulation, which leaves a white residue. In two of our three tests (species), malathion was not among the better performers.

Guthion did a fairly good job on the strawberry sap beetle and the driedfruit beetle but not against the picnic beetle. However, with a waiting interval of 14 days on raspberries and 5 days on strawberries, it cannot serve as a useful chemical protectant for ripe fruit.

Dibrom (Naled) has promise against the strawberry sap beetle and it only has a 1-day waiting period. Dibrom should be kept in mind as a possible chemical for the control of this pest in the future since it is labeled for use on strawberries.

The best approved pesticide for control of the picnic beetle on raspberries in our tests was malathion, which can be used 1 day before harvest. Likewise, the best approved material against the driedfruit beetle in our tests was malathion, considering the time between last spray and harvest for strawberries and raspberries.

**TABLE 1.—Topical Toxicity of Insecticides to Strawberry Sap Beetle Adults, Ohio, 1978.**

| | Corrected Percent Mortality* | | | |
|---|---|---|---|---|
| | Percent Concentration | | | |
| Treatment | 0.00001 | 0.0001 | 0.001 | 0.01 |
| Guthion | 0 | 5 | 58 | 97a† |
| Sevin | 0 | 0 | 0 | 8c |
| Diazinon | 0 | 0 | 11 | 0d |
| Malathion | 0 | 0 | 3 | 84b |
| Phosdrin | 0 | 0 | 16 | 82b |
| Mesurol | 5 | 3 | 8 | 97a |
| Methoxychlor | 0 | 0 | 0 | 0d |
| Dibrom | 0 | 8 | 0 | 95a |

*Control (solvent) mortality was 5%. Control (untreated) mortality was 0%.

†Percent mortality at 0.01 concentration followed by the same letter not significantly different at the 5% level DMRT.

**TABLE 2.—Driedfruit Beetle, Bioassay to Determine Efficacy of Selected Insecticides, 1981.**

| | | Percent Mortality* | |
|---|---|---|---|
| Treatment and lb ai/100 gal | | 24 hr | 48 hr |
| Diazinon 50W | 0.50 | 100a | 100a |
| Malathion 50EC | 1.95 | 100a | 100a |
| Guthion 50WP | 0.28 | 100a | 100a |
| Mesurol 75WP | 1.00 | 100a | 100a |
| Sevin 50WP | 1.50 | 39b | 41b |
| Pydrin 2.4EC | 0.15 | 100a | 100a |
| Control | | 1c | 2c |

*Means followed by the same letter are not statistically different ($P = \leq 0.05$), DMRT.

**TABLE 3.—Control of "Picnic Beetles" on Red Raspberries, 1982.**

| | Mean Number Dead/10 Insects at Time After Treatment* | | | |
|---|---|---|---|---|
| Treatment and lb ai/acre | 0 hr | 24 hr | 48 hr | 72 hr |
| Cymbush 3E 0.1 | 2.0b | 1.0b | 2.0b | 1.8b |
| Carzol 92SP 0.92 | 1.0b | 1.5b | 1.5cb | 0.5b |
| SN-72129 50 WP 0.5 | 7.5a | 8.5a | 8.5a | 7.3a |
| Mesurol 75 WP 2.0 | 8.7a | 9.2a | 8.8a | 8.5a |
| Guthion 50 WP 0.15 | 1.7b | 1.5b | 1.0cb | 2.3b |
| Vaponite 2E 0.5 | 1.5b | 0.0b | 0.3cb | 0.0b |
| Malathion 25WP 2.0 | 3.0b | 1.5b | 0.5cb | 0.0b |
| Untreated Control | 0.0b | 0.0b | 0.0c | 0.0b |

*Means in the same column followed by the same letter are not significantly different at the 5% level (DMRT).

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# Analysis of Leaf and Soil Samples from a Planting of Blueberry Seedlings Growing on an Unmulched, Upland Soil[1]

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## INTRODUCTION

The cultivated blueberry industry is based largely on the northern highbush blueberry (*Vaccinium corymbosum* L.), with its culture restricted primarily to lowlands with acidic, moist sandy soils or peat bogs (3). This exacting soil requirement has confined major production to southern New Jersey, southwestern Michigan, coastal North Carolina, and certain locations in Washington and Oregon.

Highbush blueberries can be established on upland soils if: 1) the soil is amended with peat moss, 2) the pH is lowered by sulfur application, 3) the soil moisture is kept reasonably uniform, and 4) the plants are mulched (4). These cultural practices are expensive, however, and are not feasible for many commercial situations. For this reason, the development of highbush-type cultivars adapted to upland soils has become an important goal of the USDA blueberry breeding program. Accomplishment of this goal should be possible because the germplasm needed to develop such adapted cultivars is present in a number of native blueberry species (3).

This study was initiated: 1) to determine the leaf element concentration in a range of interspecific blueberry progenies growing on an unmulched, upland soil; and 2) to investigate possible reasons for the wide variation in vigor observed between plots of the same progeny (Fig. 1).

## MATERIALS AND METHODS

In March 1982, 100 seedlings each of six progenies were pruned to a height of 10 to 15 cm and planted at Beltsville, Md., on a hillside having a Galestown fine sandy loam soil. Seven months prior to planting, the pH of this soil was above 6.0 due to a previous liming; so 250 kg of micronized sulfur was incorporated into the 0.1 hectare field. This lowered soil pH to around 4.2 by planting time. No organic matter was added to the planting furrow, and the plants were not mulched. Weeds were controlled with a combination of preemergence herbicide, cultivation, and hand-weeding.

The experimental layout consisted of 10 replications of each progeny in a randomized complete block design. Each plot consisted of 10 plants spaced 0.5 m apart in the row with 1.0 m between rows. The plants were fertilized with approximately 25 kg N/ha applied as $(NH_4)_2 SO_4$ in May and water was applied periodically throughout the summer with overhead sprinklers.

The mean canopy volume (height x width x depth) of 10 randomly selected seedlings in each progeny was determined in June 1983. The stems of these plants were then cut off at ground level, and the above-ground portion was collected for elemental determinations. Leaves were dried at 70° C for 48 hours and then ground to pass a 20-mesh sieve. Samples were analyzed for Mn, P, Mg, Ca, Fe, Cu, Zn, and K, using the procedures described by Korcak *et al.* (6).

Soil samples were collected from the most vigorous plot and the least vigorous plot of each progeny. These samples were analyzed for pH, cation exchange capacity (CEC), P, K, Mg, Ca, and K, Mg, and Ca percent saturation by the Soil Testing Laboratory, Pennsylvania State University. Appropriate statistical methods were used to determine if there were significant differences in pH, CEC, or nutrient levels between the plots with vigorous seedlings and those with less vigorous seedlings.

## RESULTS AND DISCUSSION

The mean leaf element concentrations of the six progenies sampled in this study were similar to standard values for highbush grown on commercial blueberry soils in Michigan, except for Cu and Mn (Table 1). The concentrations of Cu were approximately two-thirds lower than the standard value for highbush, but they were still within a range considered normal for a number of fruit crops (7). The concentrations of Mn, on the other hand, were two to five times higher than the standard value for highbush. These concentrations may be approaching toxic levels. Two hundred ppm is considered above normal for a number of fruit crops (7).

Korcak *et al.* (6) found a highly significant negative correlation between the concentration of soil Mn and the dry weight of blueberry seedlings. They concluded that Mn may prove to be of major significance in the establishment of blueberries in unamended mineral soils. Mn availability can be reduced by adding organic matter to the soil (2). If organic matter is not added to mineral soils, which are usually indigenously high in Mn (6), available Mn may be at levels toxic to the blueberry.

US75 x NJUS11, a progeny with a relatively high mean canopy volume (Table 1), had the lowest average Mn level of the six progenies tested. This raises the question: do some of the seedlings in this progeny have a mechanism to exclude Mn uptake? NJUS64 x G-362,

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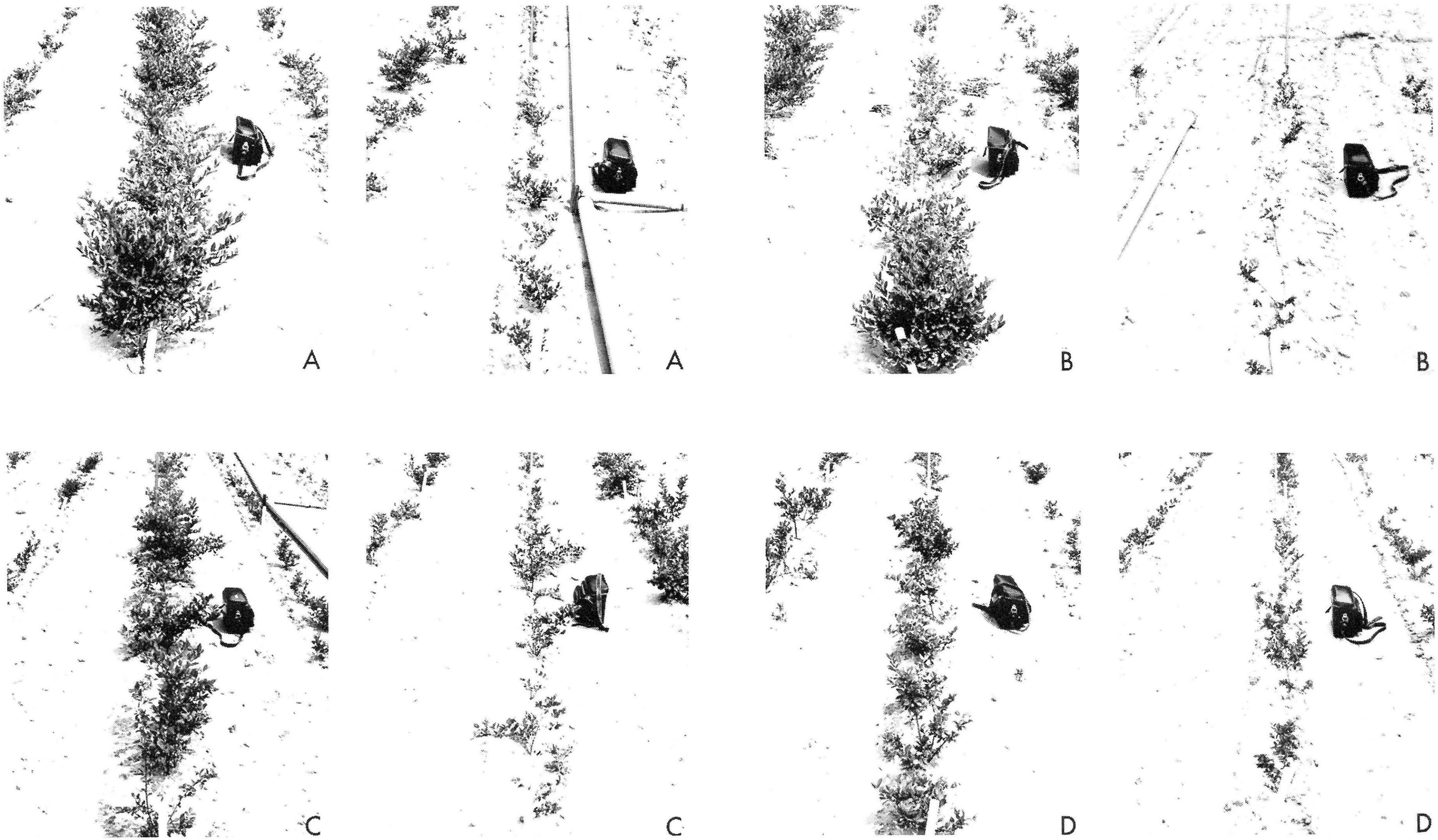


FIG. 1.—Most vigorous plot (left) and least vigorous plot (right) of: A) NJUS 11 x US75; B) US75 x US226; C) G-362 x NJUS 11; and D) G-362 x US226.

**TABLE 1.—Mean Leaf Element Concentrations and Canopy Volumes for Six Blueberry Progenies Grown in an Unmulched Upland Soil.**

| Progeny | Mn (ppm) | P (%) | Mg (%) | Ca (%) | Fe (ppm) | Cu (ppm) | Zn (ppm) | K (%) | Mean Canopy Volume ($cm^3$) |
|---|---|---|---|---|---|---|---|---|---|
| NJUS64 x G-362 | 823 | 0.09 | 0.22 | 0.51 | 264 | 5 | 24 | 0.47 | 4220 |
| US226 x G-362 | 572 | 0.09 | 0.27 | 0.55 | 258 | 4 | 25 | 0.49 | 1922 |
| US75 x G-362 | 456 | 0.07 | 0.19 | 0.41 | 219 | 4 | 20 | 0.42 | 1972 |
| US75 x NJUS11 | 331 | 0.07 | 0.21 | 0.30 | 211 | 5 | 20 | 0.39 | 3816 |
| US226 x NJUS11 | 725 | 0.08 | 0.22 | 0.48 | 242 | 5 | 26 | 0.47 | 4035 |
| US226 x US75 | 596 | 0.06 | 0.27 | 0.45 | 302 | 4 | 24 | 0.47 | 1655 |
| Established Standard Values for highbush in Michigan (5) | 168 | 0.16 | 0.28 | 0.74 | 150 | 15 | 20 | 0.53 | |

**TABLE 2.—Comparison of Soil Analyses from Plots Containing the Highest Vigor Plants with Plots Containing the Lowest Vigor Plants.**

| | pH | CEC | P* | K† | Mg† | Ca† | K‡ | Mg‡ | Ca‡ |
|---|---|---|---|---|---|---|---|---|---|
| Plots with highest vigor | 4.8 | 7.9 | 59.7 | 0.13 | 0.38 | 1.27 | 2.0 | 6.9 | 19.4 |
| Plots with lowest vigor | 4.3 | 12.5 | 40.3 | 0.13 | 0.22 | 0.95 | 1.1 | 2.2 | 8.3 |
| Level of significance of student t test | 0.11 | 0.03 | 0.02 | 0.67 | 0.22 | 0.29 | 0.09 | 0.12 | 0.06 |

*Lb per acre.
†Meq per 100 g.
‡Percent saturation.

the progeny with the highest mean canopy volume of the six crosses tested (Table 1), had the highest average Mn level. Seedlings in this progeny may be able to tolerate a high Mn level. One parent of NJUS64 is a selection of *V. angustifolium*. Other work has shown that *V. angustifolium* tends to have a relatively high tissue Mn concentration without detrimental effects (1, 6).

The CEC and the P concentration of soil samples from the most vigorous plots were significantly different from those of the least vigorous plots (Table 2). Plots with the highest vigor had a higher mean P concentration and a lower mean CEC than plots with the lowest vigor.

The significantly higher CEC of soil samples from the low vigor plots suggest that these plots are on more eroded areas of the field than plots with high vigor plants. Soil samples from eroded areas are likely to consist of a higher percentage of clayey subsoil (having a high CEC) than soil samples from non-eroded areas. A soil sample from the plot of NJUS11 x US75 with the lowest vigor consisted of 59% sand, 26% silt, and 15% clay; a soil sample from the plot of NJUS11 x US75 with the highest vigor consisted of 69% sand, 20% silt, and 11% clay.

It appears that differences in soil properties could be responsible for at least part of the wide variation in vigor observed between plots of the same progeny. Initial screening for upland adaptability should probably be done in the greenhouse, where there is more control over soil and moisture variation.

Results from this study suggest that research should be done to determine if high Mn availability is the major factor limiting the growth of highbush blueberries on upland soils. Such research could lead to the development of an efficient method for screening blueberry genotypes for upland soil adaptability.

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